UNIVERSITY OF LJUBLJANA

Faculty of Mechanical Engineering

Research of driver's perception of novel traffic signals using an eye tracker

A Master's thesis of the second-cycle master's study programme in MECHANICAL ENGINEERING – a research and development programme

Ignacio Pliego Prim

Ljubljana, June 2019

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Advisor: Assist. Prof. Dr. Miha Ambrož
Co-advisor: Assoc. Prof. Dr. Robert Kunc

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Declaration

1. I, the undersigned Ignacio Pliego Prim, born 1st of July 1994 in Barcelona, Spain, a student at the Faculty of Mechanical Engineering at the University of Ljubljana, hereby declare that this master’s thesis titled *Research of driver's perception of novel traffic signals using an eyetracker* is my own original work created under the supervision of my advisor assist. prof. dr. Miha Ambrož and co-advisor prof. dr. Robert Kunc.

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Abstract (in English)

Serial No. **MAG II/642 E**

Research of driver's perception of novel traffic signals using an eye tracker

Keywords:

- Eye tracker
- Dikablis system
- Gaze
- Driving behavior
- Area of interest
- Traffic signals
- Road safety

Novo Mesto is a small town in the Slovenian countryside which is undergoing a new project of road safety. New traffic signals are to be placed in bus stops to give drivers awareness of children standing waiting for the bus. Our mission is to use an eye tracker (the Dikablis device by Ergoneers) to study the reaction of three test drivers against these new signals; if they do detect them or not and if they modify their driving behavior once noticed them. The methodology is to do a first test before the signal placements and another one after, and afterwards compare both situations. Results are satisfying, with high values of reliability, and make us think the new signals will be useful and will contribute to make the road a safer place for children.

Abstract (in Slovenian)

Serial No. **MAG II/642 E**

Raziskava voznikovega zaznavanja nove prometne signalizacije z uporabo naprave za sledenje pogleda

Ključne besede:

naprava za sledenje pogleda
sistem Dikablis
pogled
obnašanje voznika
področje opazovanja
prometna signalizacija
varnost cestnega prometa

V okolici Novega mesta poteka projekt s področja varnosti v cestnem prometu, v okviru katerega je nameščena nova prometna siganlizacija na avtobusnih postajah, namenjena zagotavljanju pozornosti voznikov na tam čakajoče otroke. Cilj naloge je uporaba naprave za sledenje pogleda (naprava Dikablis podjetja Ergoneers) za opazovanje reakcij treh voznikov na nameščeno novo prometno signalizacijo, posebej glede njene zaznave in sprememb načina vožnje ob njej. Metodologija raziskave je vključevala izvedbo prvega preizkusa pred namestitvijo signalizacije in drugega po namestitvi signalizacije. Po izvedbi obeh preizkusov je bila izvedena analiza in primerjava med njima. Rezultati so zadovoljivi in potrjujejo zanesljivost delovanja naprave ter hkrati nakazujejo, da bo novo postavljena signalizacija lahko prispevala k povečanju varnosti otrok na cesti.

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Abbreviations

UI	**U**ser **I**nterface
AOI	**A**rea **O**f **I**nterest
PCCR	**P**upil **C**enter **C**orneal **R**eflection
NMEA	**N**ational **M**arine **E**lectronics **A**ssociation
RMC	**R**ecommended **M**inimum sentence **C**
GPS	**G**lobal **P**ositioning **S**ystem
N-S	**N**orth**-S**outh
S-N	**S**outh**-N**orth
LM	**L**eft **M**irror
RM	**R**ight **M**irror
CM	**C**entral **M**irror
LW	**L**eft **W**indshield
RW	**R**ight **W**indshield
SP	**Sp**eedometer
VR	**V**irtual **R**eality

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1 Introduction

1.1 Background and motivation

Every year, the governments strive to raise the awareness of road safety and the importance of cautious driving. Although nearly impossible to achieve, the goal of zero traffic fatalities exists and new rules, penalties and aids such as traffic signs are implemented to achieve it. The most important factor is human performance, which of course relies on each individual, but external signs can be very helpful and this is the main focus of the project: Do they really make a difference in drivers' behavior? Where should they be placed to achieve the best visibility? Starting from the hypothesis that "*Traffic signals are very useful and prevent the possibility of accidents as drivers notice them and react to them"*, a study will be carried out in the town of Novo Mesto to decide whether it is valid or not.

Novo Mesto (*figure 1.1*) is a small town in the Slovenian countryside which is undergoing a new project of road safety. New traffic signals are to be placed at bus stops to increase drivers' awareness of children standing nearby waiting for the bus. Nowadays, there are no traffic signals, which makes it difficult for drivers to notice these stops increasing the danger for the people standing there.

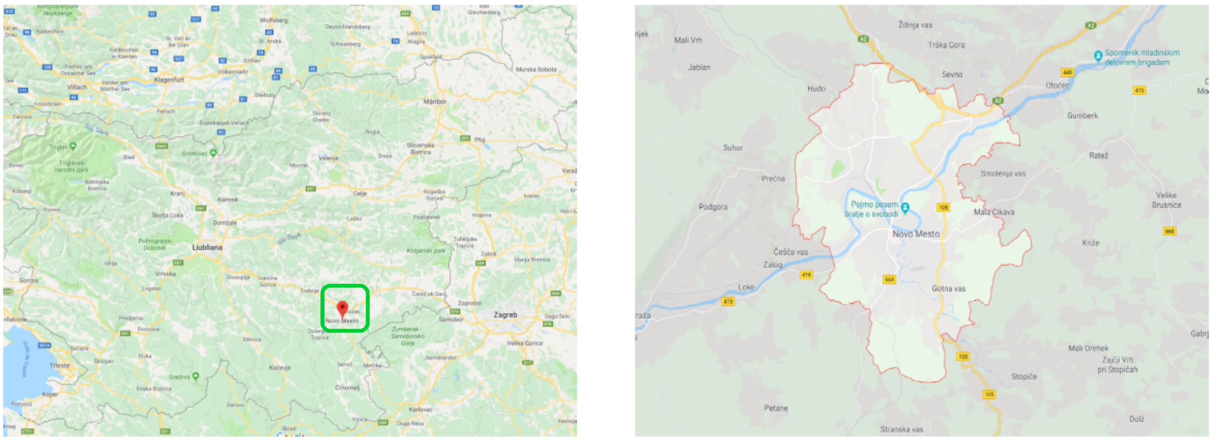

Figure 1.1: *Left picture shows the situation of Novo Mesto in the south east of Slovenia. Picture on the right displays the municipality's perimeter. Novo Mesto's surface is 236 km^2 and has a population of 36.480 habitants. The city of Novo Mesto, seat of the municipality, covers 33,3 km^2 and has 23.341 habitants. Data from the Republic of Slovenia Statistical Office [1.1] dated 2016. Images from Google Maps [1.2]*

The exact road where the signals will be placed and therefore where the study will take place is R3-664/2501. The studied length is from km 7,575 to km 16,690 *(figure 1.2)*. This stretch of road has been the site of up to 35 accidents since 2016, 13 of which took place in 2018. 50% of them were free of injuries but the other 50% were with important corporal damages. No deaths have been reported since 2006. Since 2000, there have been a total of 421 accidents, only three of which were mortal. In *figure 1.2*, accidents are represented by red circles filled with green. The letter next to them stands for the severity of the accident. Letter B is for the without-injuries type and letter L for the important-corporal-damages type of accident. Other letters not shown in *figure 1.2* can indicate serious injuries or even death. The information is extracted from the Traffic Accidents web page for Slovenia, property of the Slovenian Traffic Safety Agency [1.3].

Figure 1.2: *Road under study situated in Novo Mesto. Picture in the right zooms the green rectangle which is the recorded distance. Note the road section 2501. Small red circles filled with green represent the accidents that occurred during 2018. Images and information from Slovenian Traffic Safety Agency [1.3].*

This road consists of two lanes; one for each direction. During most of its path, the lanes are not distinguished with white lines. There are not many traffic signals along the entire road and visibility

is decreased due to several changes in road grade. At more than one point, it also crosses the rail tracks and there is no signaling for that *(see figure 1.3)*. All this, alongside the non-signalized bus stops, make it a dangerous road with a high accident risk.

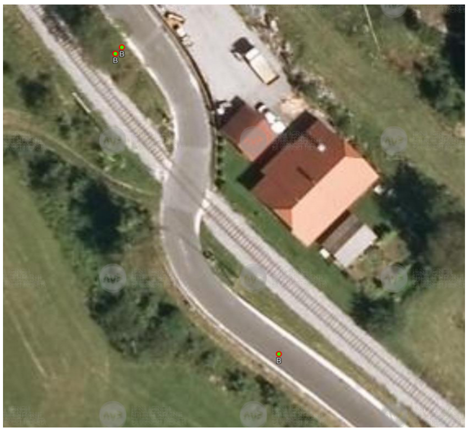

Figure 1.3: *Crossing between the road and the train tracks. Note that no traffic signals are present. Image from Slovenian Traffic Safety Agency [1.3].*

There are two types of signals that will be placed. They both have the same structure: a vertical pole with a horizontal post at the top which has the picture of two kids and a bus *(*see *figure 1.4)*. The only difference between them is that some have lights on top and the others do not. The lights launch automatically as they detect the proximity of a special device. This device will be distributed to kids so that when they approach the bus stops, the signals will light up indicating their presence. The other signals are static. The signals are distributed as follows (*Table 1.1)*:

Table 1.1: *Distribution of the traffic signals along the road section.*

Nº	Km	Type (L-with lights; S-static)
1	7,635	L
2	9,450	S (two signals, one for each direction)
3	10,565	S
4	11,040	S
4a	11,720	S
5	11,775	S
6	13,440	L
7	15,640	S
8	16,358	S
9	16,700	S

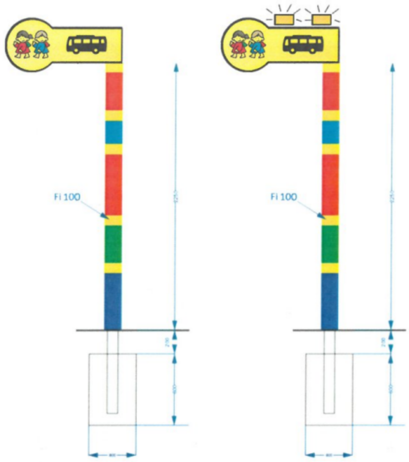

Figure 1.4: *Traffic signals implemented. Note the difference between the static ones (left) and the lighting ones (right). Image property of Cestel.*

The scenario is now defined. Ten signals along 9,1 km of road to make a safer way to school for children. Our mission, to monitor and analyze the drivers' behavior against this new traffic signals to prove their validity.

1.2 Objectives

The thesis is structured the following way: *Chapter 2* includes all the background research done in relation with the eye tracking technology which concerns this work. Scientific papers and studies on eye tracking devices including system, methodology and applications, devoting in particular to those applied to driving tests. It also incorporates a brief explanation of the previous work done by myself: *"Research of driver's perception of traffic using an eye tracker"[1.4].* All of it to understand the progress achieved to date and the possibilities it has. *Chapter 3* contains all the applied methodology. First a complete review of the eye tracking system used. Understanding the operation of the device perfectly its crucial to use its full potential and achieve the expected outcome. Next the experimentation accomplished step by step; from the experimental set up to the analysis of the obtained data. In addition there is also a sub chapter considering the assumptions and faced limitations. Overcoming this limitations which will be presented in this chapter is decisive in the execution of reliable experiments. Next, *Chapter 4*, exhibits the obtained results. All the possible information that can shed light on driving behavior, its strengths and weaknesses. Where do the test people spend more time looking? Are there a lot of distractions while driving? Do the new traffic signals make a difference on where people focus? This questions and more are expected to be answered here. *Chapter 5* discusses the results and the possible future improvements. Chapter 6 ends with a conclusion of the project with some key aspects to understand it and its scope. Finally, *Chapter 7* displays all the used bibliography and references with acknowledgement to its authors.

2 Theoretical background

2.1 Past and present of eye tracking

Eye tracking origins date back to 1879 when the French ophthalmologist Louis Émile Javal noticed that readers’ eyes do not go through words in a text fluently but make quick movements mixed with short stops. But it was not until 1908 that Edmund Huey built the first device for eye tracking while reading. This device was invasive as readers had to wear some type of contact lenses. In 1967, Alfred Lukyanovich Yarbus published *Eye Movements and Vision* [2.1]. Using his eye tracker (*figure 2.1, a),* he dealt with the perception of images which are strictly stationary relative to the retina, the principles governing the human eye movements, and the study of their role in the process of vision. This book was highly influential and lead to great improvements in the following years. The research on eye movement and eye tracking thrived during the 1970s and 1980s. In the 1970s, the eye trackers became less intrusive, more accurate, and able to separate eye from head movements. In the 1980s, computers became powerful enough to do eye tracking in real time, which enabled application of video-based eye trackers to human-computer interaction. During this time, marketing groups began using eye-tracking to measure the effectiveness of ads in magazines. Eye-tracking was able to determine what parts of a magazine page were seen, which elements of the page were actually read, and how much time was spent on each part. Since 2000s, as eye tracking technology has continued to evolve, applications have spread to nearly every area of life to get to know human behavior through its eyes and use it for business and scientific purposes. This technology has seemingly become far more popular in the past decade than any other time in history, and is heavily used in developing effective advertising campaigns and usable websites. Even so, access to this technology remains far beyond the average, with the eye-tracking hardware often priced in the tens of thousands of dollars.

This evolution also enables clear ergonomic improvements. From invasive and comfortless to non-invasive and external devices. *Figure 2.1* shows three examples sorted by their appearance in time. As can be seen, the device used in this project (*figure 2.1, b)* is not the newest as it dates from 2009,

a) *b)* *c)*

Figure 2.1: *a) Yarbus eye tracker. 1967. [2.1] b) Dikablis Eye tracker by Ergoneers. Head-unit and recording computer. 2009. It is the one used for the recordings in this project. c) Tobii Pro Nano eye tracker. 2018. Totally external to user.*

and further improvements in precision and image have been carried out. The eye tracking device used is the non-invasive head unit Dikablis from the Ergoneers company. Founded in 2005 and specialized in eye tracking systems, it is an important international partner for the transport and automotive sectors, market research and usability, science and research, sports and biomechanics. The complete device is reviewed in *Chapter 3: "Methodology"*.

Application of this technique to observe driving strategies also dates back to the 1970s. Already in 1971, Soliday published a survey of reports on the studies of drivers [2.2]. At that time, studies on the differences in visual strategies of the experienced and novice drivers started and the concept of “conspicuity” was coined, denoting the ability to perceive an element, associated with a concept of the functional field of vision. In 1977, Cohen AS et al. [2.3] published a study of eye movements while driving cars around curves, testing both experienced and inexperienced drivers. Among other results, he found out that mean duration of eye fixations of experienced individuals was shorter while driving in a curve to the right, but their amplitude of eye movement was greater in a curve to the left than that of inexperienced drivers. Shinar D et al. also did research on driving through curves, publishing a paper also in 1977 [2.4]. They start from the definition of Fry [2.5] which suggests that the most precise directional information is given by the focus of expansion; that point in the moving visual field straight ahead of the driver where objects appear stationary. Results show how instead of concentrating his fixations -and presumably his attention- close to the focus of expansion as he does on the straight road, on a curved road the driver concentrates intermittently on the position of the road ahead and the road edge (lane markings) closer to the car. Fry states that if the driver was to do the same as in a straight path, he would very quickly go off the road due to the quick changes in the relationship between the direction of the road and the focus of expansion. Conclusion is this is especially true because most curves are parabolic rather than arcs of a constant radius.
More recent studies focus more on the driving aspects such as fatigue and risk detection. In 2005, Anuj Kumar Pradhan et al. [2.6] evaluated the effects of driver age on risk perception. Comparing three groups of different aged people in different risky road situations, they concluded inexperience has a great effect in accident possibilities and the younger and inexperienced group is up to nine times more likely to suffer an accident than others. Older drivers between the ages of 60 and 75 are much more likely to attend to risk relevant areas than drivers in either of the younger groups. In 2008, Mandalapu Sarada Devi et al. [2.7] focused on drivers’ fatigue as it is one of the biggest

causes of accidents. The authors designed a system that uses a video camera that points directly towards the driver face in order to detect fatigue. They worked on the video files recorded by the camera. A video file is converted into frames. Once the eyes are located from each frame, by measuring the distances between the intensity changes in the eye area, one can determine whether the eyes are open or closed. If the eyes are found closed for 5 consecutive frames, the system draws the conclusion that the driver is falling asleep and issues a warning signal. In 2010, Oskar Palinko et al. [2.8] published an article about estimating cognitive load using remote eye tracking. First introduced by Iqbal et al. [2.9], they emphasize the term ‘pupillometry’. Measuring the percent change of the pupil size, they got to the conclusion that complex tasks resulted in higher values of this level indicator.
Application of the Eye tracking technology measures attention, interest, and arousal, making it a great tool for all types of research which directly or indirectly deals with human behavior. Nowadays, it can be successfully applied in a variety of fields such as psychology, medicine, marketing, education, gaming as well as for enhancing human-computer interaction by using the eyes for navigation and controls. With the help of eye-tracking systems, it is possible to detect what users are looking at and anticipate what they want to do next, opening up a whole series of new possibilities for intuitive interaction between a human and a machine. For example Tobii Gaming, a division of Tobii Eye Tracking Company, already allows to monitor the video games camera and gaze movements with its newest eye trackers. Sports is another interesting field for eye tracking. Analyzing an athlete’s individual performance by identifying a correlation between their area of focus and the individual’s actions during a game can enable distinguishing gaze patterns for a better performance. Another application is in Virtual Reality, a field which is under extensive study. It will significantly enhance the VR experience for customers by allowing avatars to reflect our eye movements and the emotions we convey.

2.2 Eyetracker setup and testing

Before facing this project, there was some previous research and experimentation with the Dikablis device for the purpose of learning all its capabilities and extract all its potential. This work was to complete a Master Practicum for the University of Ljubljana with the title "*Research of driver's perception of traffic using an eye tracker"* [1.4].

One driver was tested along three different paths in the same closed circuit to observe his behaviors against traffic situations such as lights, roundabouts or crossroads. The results were satisfactory in terms of eye detection, which was above 95% in the analyzed circuits. Calibration was correct but it could be improved as it is one of the most important factors to consider; we want to know every moment the exact point being observed. One of the crucial aspects was marker detection. It failed sometimes due to too much or insufficient light, which makes it difficult to see the contrast between black and white. If markers fail, then so do the areas of interest as they are linked to them. The right and left mirror are the markers which miss recognition more as they are outside the car receiving light directly. The terms marker detection and AOIs are explained in *chapter 3: Methodology.*

The followed methodology back then is explained in *table 2.1*:

Table 2.1: *Methodology in Master Practicum*

1. Preparing the experiment scene	Test subject wearing the head-unit. Laptop and test leader on position in the car to record. Markers positioned in specific locations.
2. Before and during driving: Dikablis Recorder	Achieving the best pupil recognition possible, gaze calibration and recording of the test data.
3. After recording: Dikablis Analysis	Re-process the data. Re-calibration and improving of pupil detection.
4. Marker detection	Runs automatically through all the videos and detects the markers.
5. D-Lab	Import all the recorded data. Definition of combined markers and Areas of Interest. Compute gaze behavior. How many times and for how long the subject is looking at each AOI. Eliminate blinks, eliminate cross throughs. Obtain results and statistics.

The methodology used in the thesis is the same with some improvements, so all the aspects from this table are reviewed in the thesis for a better understanding.
Some interesting conclusions were extracted from the Practicum, mostly those which concern learning the positive and negative aspects that influence the collection of data in the recordings. The eye is constantly moving at high speed and even more while driving a car as being able to control all your surroundings is mandatory. That worsens the quality of the eye tracker, which easily loses track of the pupil. Sunlight can also be a problem if it is too shiny. On the test day, the sun was shining bright, so the pupil had more reflections and changes of size than usual. That caused a serious problem with the pupil detection as shown in *figure 2.2*. With this condition, it was impossible to achieve more than 60% of eye detection. In the worst case, the second circuit, detection was around 40%. Good aspect of the system is Dikablis Analysis, which allows post-recording improvement of pupil detection, automatic or manual. With automatic detection, the recognition improved by only 10-15%. The manual option raised detection to 95-96%, even though it is a long and tedious process which would be better to avoid. Due to this limitation, only two of the four initial circuits have been analyzed: the first route in the first circuit and the way back to the faculty. Both with pupil detection higher than 95%.

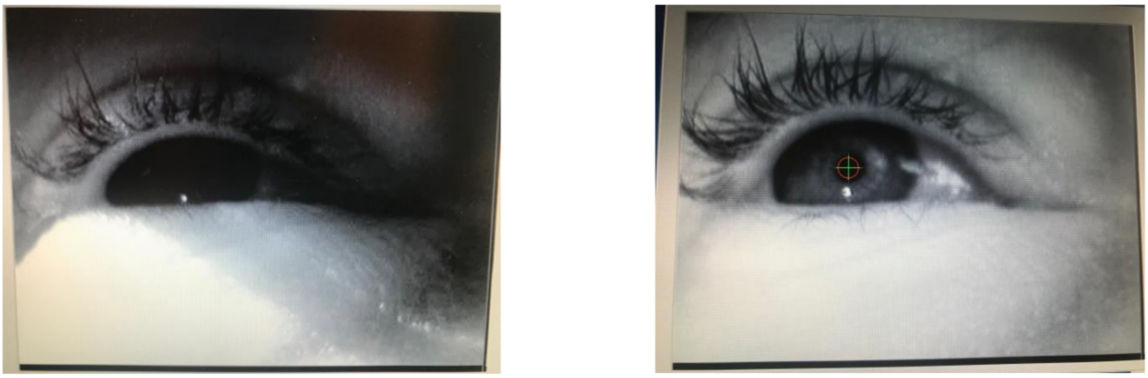

Figure 2.2: *Comparison between eye in a bad detection frame (left) and a perfect detection frame (right).*

Marker detection also fails sometimes due to too much or insufficient light, which makes it difficult to see the contrast between black and white. If markers fail, then so do the AOIs as they are linked to them. The right and left mirror are the markers which miss recognition more as they are outside the car receiving light directly.

A few results were also obtained at first contact with D-Lab software. *Table 2.2* shows the AOIs percentage of fixation, or whats the same, the time the drivers are looking at each defined area of the car. *Figures 2.3 and 2.4* are graphic presentations of the changes of gaze along time. As expected, the front screen gets most of the attention and speedometer is reviewed quickly at some points. But rear view mirrors have fewer time intervals than they should. That is because AOIs are smaller and only linked to one marker which is the outside marker. A better option now would be combining the outside marker with the one inside. From the duration of gaze inside AOIs, the percentage in each AOI can be calculated, the mean between the two routes:

Table 2.2: *Master Practicum: Gaze percentage of each AOI*

AOI	Front screen	Left rearview	Right rearview	Speedometer	Cent. Rearview
Gaze %	45%	4%	1,5%	3%	0%

Obviously, the central rearview is not recognized correctly as it is impossible to have 0%. This is because of the poor marker detection it has and because of the calibration of the gaze, which can be a bit inadequate as it never reaches the mirror. This emphasizes the importance of the first steps before recording when calibration and pupil recognition are done.

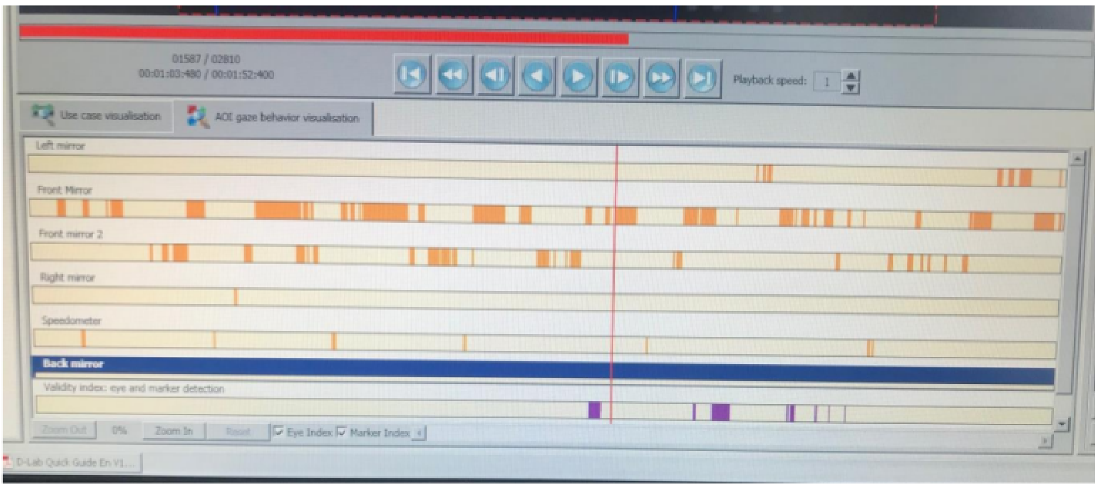

Figure 2.3: *Gaze behavior Circuit 1 [1.4]*

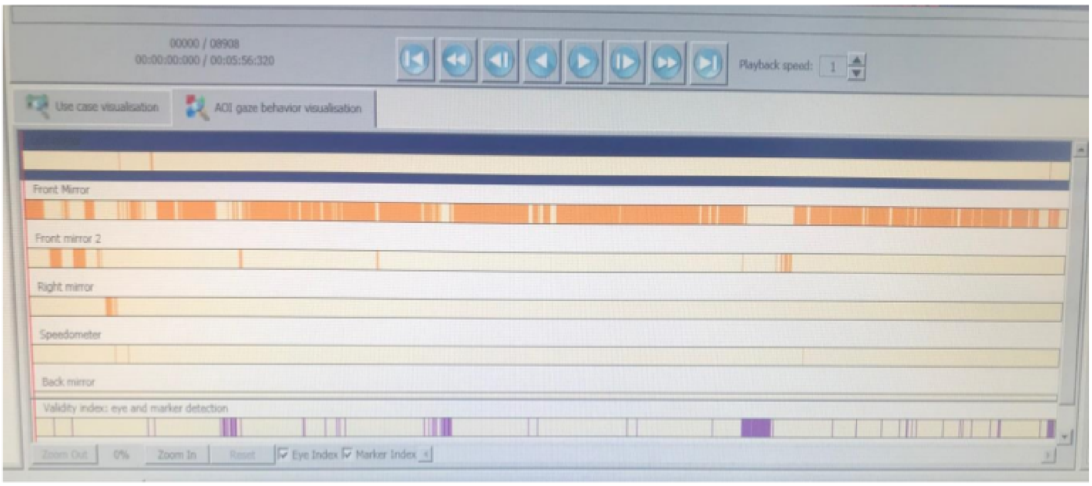

Figure 2.4: *Gaze behavior Back to faculty [1.4]*

3 Methodology

3.1 Outline

Recording, editing and analyzing the data is a complex process where several elements take part, so the following outline enables an easier visualization for a better understanding of the system (*figure 3.1*). In this chapter, each element is reviewed in detail, starting with the device breakdown into its different components, followed by the recording, post-processing and analysis of the data.

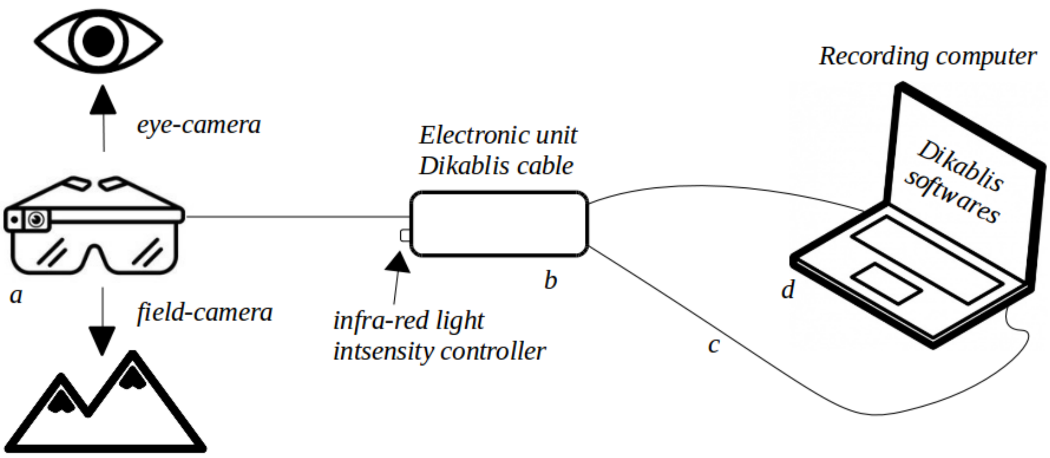

Figure 3.1: *Outline of the Dikablis hardware system components and its connections.*

Looking at the outline, we realize that it is a wired system from the head unit to the recording computer. This means the subject and the experiment master have to be together. Even so, the cables are long enough to have the test person in the driving seat and the experiment master in the back holding the computer; the chosen situation. The experimenter also holds the electronic unit as he has to adjust the infra-red lights intensity to achieve the best pupil detection.

3.2 Dikablis system

As mentioned before the eye tracking device used is the Dikablis head unit from the Ergoneers company. The Dikablis system includes both necessary hardware and software [3.1].

3.2.1 Hardware

The hardware is composed of the non-invasive head unit (*figure 3.1, a)*, the recording computer (*figure 3.1, d)*, the electronic unit Dikablis cable *(figure 3.1, b)* and the connection cables (*figure 3.1, c)*. The head-unit has all the required components to capture correctly the pupil and the gaze. Focusing on the eye, there is a camera (eye-cam) which records in black and white constantly with the help of a nearly-infrared light diode that ensures the optimal illumination of the eye region. Focusing on the field of vision of the test subject, there is another camera (field-cam) which also records in black and white. The focus of the field camera can be adjusted by rotating the lens until making sure the markers can be clearly seen. All the head-unit components can be easily adjusted through screws to have the most accurate perspective of both cameras. The electronic-unit Dikablis cable oversees connecting the head-unit with the computer and contains a rotatory button to regulate the intensity of the LED. The recording computer is a laptop which incorporates all the software necessary to record the drive and to process and analyze it afterwards.

3.2.2 Software

The software is composed of three individual systems which can be started on demand. The Dikablis recording software is the main governing module. With this module, test data is recorded. The reprocessing of the test data is carried out with the support of Dikablis Analysis software. Dikablis Player is used to display the collected data. There are three more software packages for extending the analysis: D-Lab, Control Center and Marker Detector. Control Center can be used to control the Dikablis Recording. After this, the data can be imported to D-Lab for evaluation. The software packages used for this work are shown in *figure 3.2* in order of appearance.

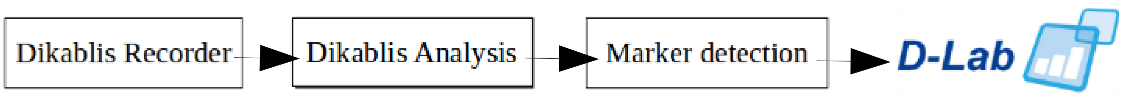

Figure 3.2: *Softwares for recording, processing and analyzing the data appearing in the order they are used. Recorder is in charge of the pupil detection, gaze calibration and recording the video. Analysis is for post-processing the collected data. Marker detection runs over the recorded data to distinguish the positioned markers. This markers are helpful for analyzing the video later. D-Lab is the last software for analyzing and obtaining the results. All softwares functionalities will be reviewed next.*

3.2.2.1 Dikablis Recorder

As its name says, it is in charge of the recording. But before the recording begins, there are two very important steps to be considered which determine the quality of the recording and its reliability: eye detection and gaze calibration, both of which are also done with the Recorder Software (see *UI in figure 3.3)*.

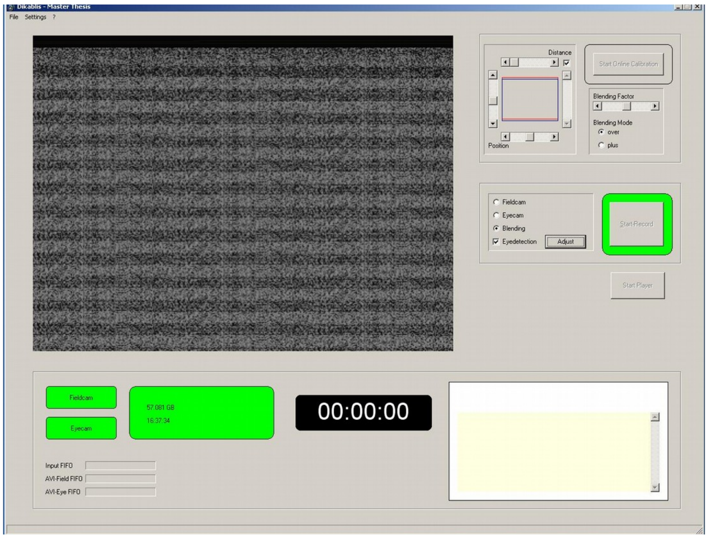

Figure 3.3: *Dikablis Recorder UI*

The objective of the eye detection is to separate the pupil from the rest of the eye by thresholding. Thresholding is a method of segmentation used in gray scale images to isolate the needed pixels by setting a threshold value. If pixel's intensity is below this value it is replaced with a black pixel, and if it is above the value, its replaced with a white pixel. This value can be adjusted by moving the scrollbars above and below the histogram *(see right image in figure 3.4)*. The result of the pupil detection shown in the left window will change according to the limits you set *(see left image in figure 3.4)*. Filtered pupil is the black area in the filtered pupil window (also shown in red in the left window).

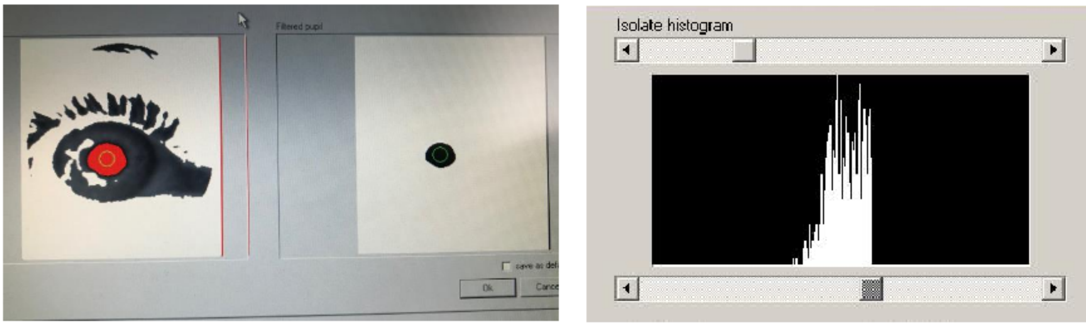

Figure 3.4: *Eye detection in the Recorder software. Left image shows the detected pupil. In this case its perfect as no other areas are colored in red or appear in the filtered pupil window. In the right image the histogram for isolating the pupil is displayed. Note also the green circle in the left image which indicates the correct detection. If this circle is no longer visible detection is failing.*

But how does the head unit work to get this images? Near-infrared light is directed towards the center of the eyes, causing detectable reflections in both the pupil and the cornea (the outer-most optical element of the eye). These reflections are tracked by an infrared camera. This is known as *PCCR*. This infra-red light allows a precise differentiation between pupil and iris, as its light enters directly to the pupil while it bounces off the iris. Besides infra-red light is not visible for humans so it doesn't cause any distraction while to the eyes while being tracked. Normal light sources aren’t able to provide as much contrast and also can create confusion, meaning that an appropriate amount of accuracy is much harder to achieve without infrared light.

During the calibration process the correlation of the images from the eye and field camera and the plane of calibration are adjusted. The glance behavior is always calibrated at one particular plane and at a constant distance away from the eye. The system works very accurately at this plane. If the test person is looking at objects not included in this plane, the accuracy decreases. Calibration based on the plane of analysis is sufficient for the majority of applications. The calibration window is shown in the top of the Recorder window *(figure 3.3)*, and enlarged in *figure 3.5* for better understanding. Position settings adjust the vertical and horizontal position of the cross-hair. Symbolizes the viewing direction. Distance settings adjust the distance between the eye and the plane of analysis. The closer the plane, the greater the eye image is scaled, as the cross-hair must reach further distances with each movement.

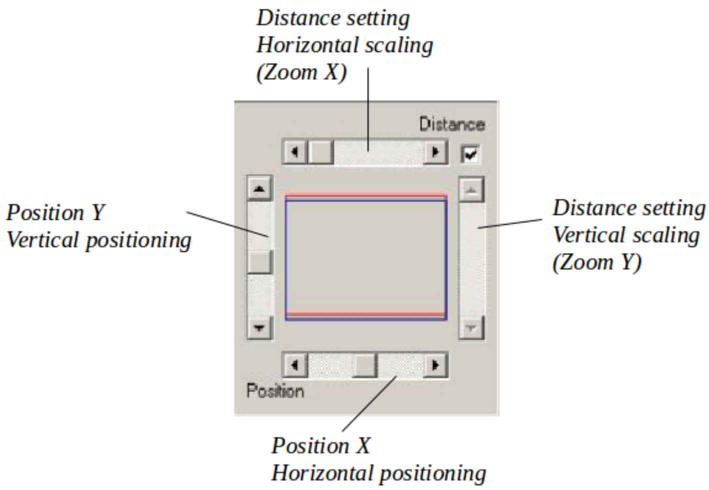

Figure 3.5: *Calibration window. Image from Recording software.*

Once the settings are ready, it is time to record by pressing the green start record button found in the Recorder UI *(figure 3.3)*. While recording, the user can choose to display in the screen the view of the field cam, eye cam or a blending of both.

3.2.2.2 Dikablis Analysis

This software takes a really important role as it allows the processing of the recorded videos. Pupil detection is not always perfect, and with Dikablis Analysis percentages of detection can reach values up to 90% or more. It also permits re-calibration of the gaze if it does not point exactly where it is supposed to. This processes are really long and tedious so that is why good eye detection and calibration during the recording are so important. *Figure 3.6* shows the UI. It can be observed that both manual and automatic eye detection are possible.

Automatic detection allows to modify again the threshold value (*histogram values in figure 3.4*) and run through the entire video or only those frames which do not have any eye detection. It is really good to increase detection in short time but it usually needs some final help from the manual method to get to the high detection rates (90-100%). In the manual method, as the name says, it is the user who detects the pupil and must click on its center to position the cross-hair. Each click modifies one single frame and every second consists of twenty-five frames. It is a long process where you can achieve great precision results but at great time cost.

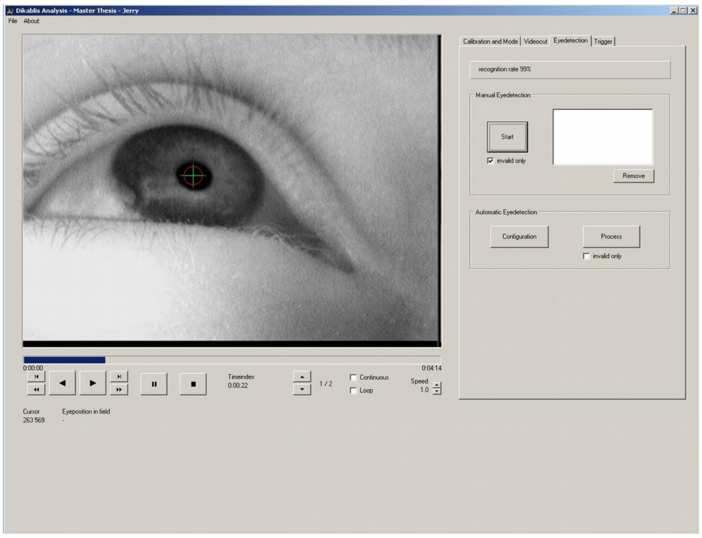

Figure 3.6: *Dikablis Analysis UI. Its function is to re-calibrate and re-detect the pupil in those moments it failed during the recording. It also has the video cut option for cropping the undesired sequences. It provides the percentage of eye detection. In this short test video, its 99%. Image from Analysis software.*

3.2.2.3 Marker Detector

Markers are used as reference points in the environment. Best placement is in strategic locations which will be useful for creating areas of interest -explained in the next chapter- in the analysis with D-Lab *(see chosen location of markers in figure 3.9)*. These markers are black and white geometric figures with different shapes and they have a name already associated. Each marker chosen for a recording has to be different from the rest. *Figure 3.7* gives some examples.

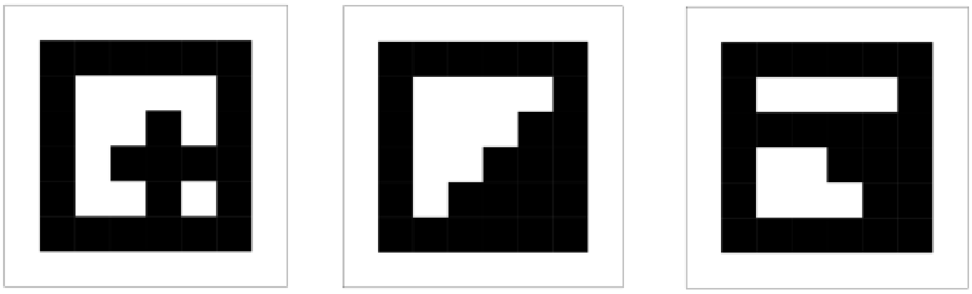

Figure 3.7: *Marker examples. Names from left to right: VIENNA, LONDON, BERLIN. [3.2]*

This markers allow transformations from fixations in field cam coordinates into marker coordinates so that it can compensate the inevitable head movements and keep the sight cross-through well located. Marker Detector is in charge of processing the video files and recognizing the markers for their future use. When playing the videos in D-Lab the detected markers appear framed in red *(note in figure 3.8)*.

3.2.2.4 D-Lab

D-Lab allows to plan, measure and analyze your experiments both individually and systematically. In this project, it is used to analyze the recorded data with all the range of module-specific analysis functions it offers. As all the files of the project are saved in the same folder, data can be imported all together into D-Lab after going through the marker detection. In *figure 3.8*, D-Lab's UI is presented. As shown in the left window, all the files concerning this project are imported. Each one contains an online recording which corresponds to the video without post-processing and an offline recording which has been modified with Dikablis Analysis.

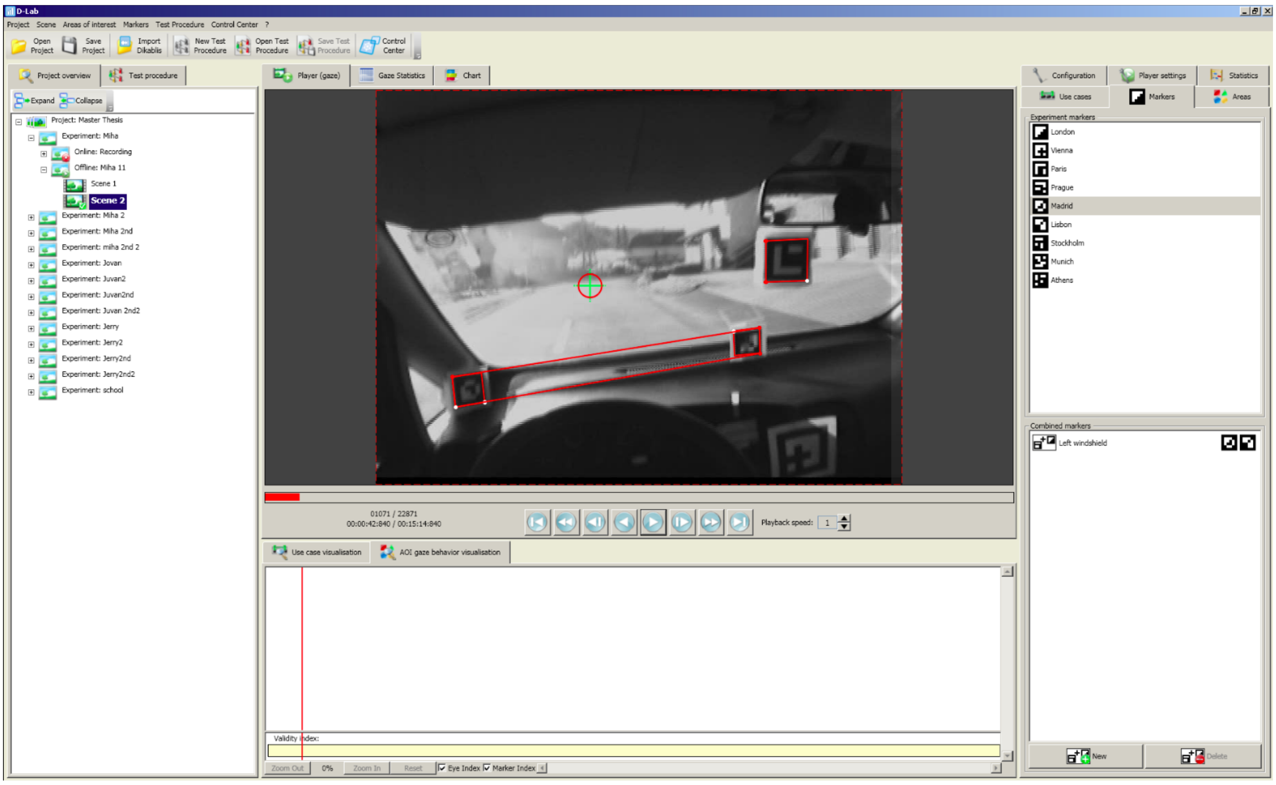

Figure 3.8: *D-Lab UI.*

In the center of the main window, the recorded video in the field camera is shown. Cross-hair pointing the gaze can be observed as well as the markers. If markers are detected at that moment, they are framed in red, otherwise they are not. The video can be replayed forwards and backwards. It is also possible to jump forward or backward one frame. The corresponding symbols can be found at the bottom of the window. On the right side, we can see several tabs with different functions; configuration, statistics, use cases, markers, etc. This will help the analysis of the data. At the bottom of the UI, there is a window which shows the gaze behavior - what AOI the subject is looking at, in which exact moment and for how long. This way we can know if the test persons are noticing the traffic signals or not; or what captures their attention at every moment.

The most important analysis method for our purpose are Markers and Areas (AOIs). In markers, all the detected ones are listed. They can be combined so that when at some point it detects one of them, it automatically does it for the connected ones. This function is really useful for AOIs. These can be created in three different ways:

· *"Marker bounded"*: they are linked to the markers and displayed every time one of those markers is recognized. Always used when the eye tracking data are to be automatically calculated in relation

to the AOIs using the markers. These will be the ones used for this project, as AOIs are not fixed and depend on the head movements and therefore the view of the field camera.
· *"Fixed"*: always anchored in the same position in the field video. Useful when the head movement is to be ignored.
· *"Manual"*: glances to the position of interest are to be set manually. Used when no markers are used and you would still like to evaluate glances at certain AOIs or those directed at moving objects are relevant.
For this project head movement is important as it is in constant rotation due to road attention. So the first principle of creating AOIs (*"marker bounded"*) is used. The defined combined markers and AOIs are explained in *Chapter 3.3: Experimental section*. Once all is defined, by pressing the "Compute gaze behavior" button data is processed and gaze behavior is displayed in the window below.
To increase precision, D-Lab has two automatic functions:
· *"Eliminate blinks"*: When a person blinks, the eye is closed for several milliseconds, meaning that no pupil recognition is possible for this period. If the test person blinks while glancing in a particular direction, this will lead to a split in the glance. Deleting blinks can prevent this from happening. The standard-compliant default setting for this is 300ms. To do so, "Eliminate blinks" button must be pressed.
· *"Eliminate cross throughs"*: A "cross through” is a very short sequence of glances at an AOI which cannot however be regarded as a proper glance. The test person's gaze simply wanders past an AOI, which does not mean that he or she has glanced directly at it. "Fly throughs" can be eliminated by pressing the "Eliminate Cross Throughs" button. The standard-compliant default setting for this is 120 ms.

3.3 Experimental section

3.3.1 Design of the experimentation

As explained in "*Chapter 1: Introduction"*, the experimentation is composed of two driving sessions in the referred location *(see chapter 1.1: Background and motivation)*. The first drive is performed before the signals are placed and the second one afterwards. For obtaining more reliable results, three test subjects will do the same route on the same day one after the other; being only the driver and the experiment leader in the car. The subjects are not informed about the purpose of the driving so it does not modify their driving or their way of paying attention to external stimulus. The three subjects are males, between 25 and 35 years old and with at least 7 years of driving experience. They will be referred to as test subjects A, B and C.

The experimentation consists of recording, processing and analyzing. Before recording the experiment, it must first be prepared. *Figure 3.8* shows the car set up with the markers positioned. *Figure 3.9* shows the test subject in position and the experiment master in the back with the recording computer. Also, a GPS is connected to the computer via USB and placed on top of the car via magnet to monitor the location and speed at every moment. These conditions are maintained for all recordings.

***Figure 3.9**: Car setup. Markers positioned in the left, center and right of the car front. There are 9 markers in total. Each one has to be unique; if not AOIs would be unstable or badly defined.*

Markers are placed with the help of foam structures to adapt to the car surfaces and secured with adhesives so that they do not move during the car movements. For the best detection, they must be the perpendicular to the field camera. Note in *figure 3.8*, the chosen orientation is always facing the drivers head. Keeping the car distribution the same is crucial to further analysis as the same conditions must always be met.

***Figure 3.10:** Left picture shows the recording computer ready to videotape in the back seat. Right picture displays the test subject in the drivers seat with the head unit on position.*

3.3.2 Recording

The first steps in the recording are the eye detection and gaze calibration. This has to be done on-site before every recording. All eyes are different so the best detection has to be achieved in every case. As explained in section *3.2.2.1 Dikablis Recorder*, eye detection is all about differentiation between pupil and iris. The infra-red light helps but the presence of bright sun can really deteriorate this distinction and make it impossible to see where the test subject is looking at. While driving, eyes move constantly and sun impacts the eyes from every angle so this situation tends to happen. The eye detection results are presented in the next chapter (*see table 3.4*) with its improvements. For the gaze calibration, four spots making a rectangle in the same plane were used to position the cross-hair horizontally and vertically and at the correct distance to the eye.

Once the setup is done, the recordings are ready to be performed. The first one took place on 21 March at 8 am, when the children of Novo Mesto make their way to school on the bus. The second recording, after the traffic signals were placed, took place on 14 May at 8 am. *Table 3.2* and *Table 3.3* present the details of the recordings for each subject. For each day, every driver has two recordings which correspond to the same path driven in both directions. That makes a total of 12 recordings for the whole project sized 11.0 GB of data and 136 minutes of video. All videos contain both field and eye camera perspective.

At the same time, the GPS is also working. The GPS provides a NMEA sentence: Recommended Minimum Data for GPS (RMC). Every row of data looks like the following comma separated value sentence:

$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A

Table 3.1: *Description of every element of data of the NMEA sentence returned by the GPS. Information from NMEA data [3.3]*

RMC	Recommended Minimum sentence C
123519	Fix taken at 12:35:19 UTC
A	Status A=active or V=Void
4807.038,N	Latitude 48º07,038' N
1131.000,E	Longitude 11º31' E
022,4	Speed over the ground in Knots
084.4	Track angle in degrees True
230319	Date: 23/03/2019
003.1,W	Magnetic variation
*6A	The checksum data, always begins with *

This data will be modified according to the necessities and processed in Excel. Time, geographical location and speed will be the important parameters to be taken into account in the analysis.

Table 3.2: *Details of the 1st drive for the three test drivers. Data obtained from the GPS.*

1st recordings. 21st of March. Recording before traffic signals are implemented.				
Tests subject	**Time [am]**	**Duration [min]**	**Avg speed [km/h]**	**Max. speed [km/h]**
A	08:15:10	12,3	44,4	65,3
	08:29:55	12,4	44,0	69,1
B	08:45:12	12,6	43,3	70,1
	08:57:10	9,9	55,2	69,9
C	09:20:33	12,7	43,0	80,9
	09:33:55	12,2	44,7	79,2

Table 3.3: *Details of the 2nd drive for the three test drivers. Data obtained from the GPS.*

2nd recordings. 14th of May. Recording after traffic signals are implemented.				
Tests subject	**Time [am]**	**Duration [min]**	**Avg speed [km/h]**	**Max. speed [km/h]**
A	08:07:10	10,5	52,2	74,8
	08:18:14	12,8	43,6	71,9
B	08:43:23	10,1	52,2	72,6
	08:54:36	10,5	54,1	83,2
C	09:10:41	11,0	48,5	77,3
	09:21:53	12,2	47,0	84,6

These tables give some relevant information but not many conclusions can be made here as many factors can be influent. For example, on the first recording the road was under some construction work so cars may had to stop for some time, and this situation distorts the results.

The duration means are 12.01 and 11.18 min with standard deviations of 1.05 and 0.44 min for the first and second recording, respectively. These are similar results, but the second recording is faster; which could mean the drivers are already familiar with the road. The interesting part is the maximum speed reached. In all recordings - mostly in the 2nd one – the speed is higher than 70 km/h, which together with the road characteristics makes it difficult to react to a risky situation, such as a child standing alongside the road.

3.3.3 Processing

Dikablis Analysis software is in charge of processing the recorded videos. Both automatic and manual techniques were used to get the best solution. *Table 3.4* summarizes the results obtained in eye detection both before and after the processing. High improvements can be appreciated.

Table 3.4: *Pupil recognition rate for every test before and after Dikablis Analysis performance.*

		A		B		C	
		Before	After	Before	After	Before	After
1st recording. 21st of March.	North-South	35%	**90%**	33%	**90%**	46%	**90%**
	South-North	70%	**92%**	40%	**96%**	65%	**96%**
2nd recording. 14th of May.	North-South	66%	**94%**	35%	**97%**	86%	**94%**
	South-North	96%	**96%**	45%	**96%**	85%	**92%**

If we take a look first at the "Before" recordings, we can observe how values are within a very broad range (33%-96%) and differ a lot in each test. We can also note that the second recording recognition rates are significantly higher than the first ones, except for test subject "B". There is an explanation: on the first day, the sun was shining bright, while on the second day the weather was cloudy. Cloudy weather avoids any reflections so it is possible to reach recognitions up to 96% without processing, as we can see in test subject "A" second recording. Detection for subject "B" was really difficult as his pupil-iris combination did not offer a lot of contrast. That translates into considerably bad recognition rates. The following images (*figure 3.10*) show two examples of impossible detection due to the sunlight and its changes of influence direction:

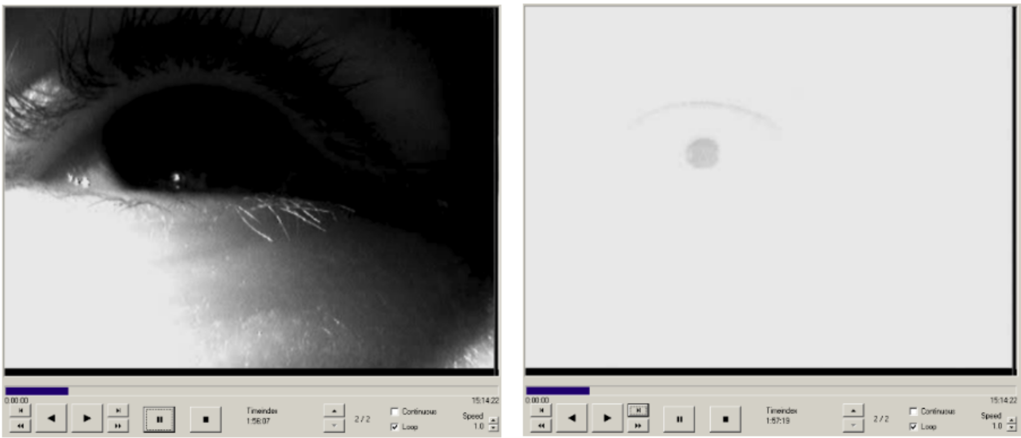

Figure 3.11: *Two frames of the video. See how it is impossible for the software to separate the pupil from the rest. This is where the manual method for detection has to be used. Image from Analysis software.*

The "After" columns refer to the processed data. In the case of 90% and higher, we consider detection precise enough for our study. Normal subjects (not dry eyes) blink around 15 times per minute, contrasted in the recorded videos. These blinks last from 0.1 to 0.4 seconds depending on each person. That means eyes are closed from 2.5% to 10% of the time. This is the criteria to only accept the 90% rate or more.

As explained before (*Chapter 3.2.2.2 Dikablis Analysis*), to achieve such results automatic and manual processes have been used. The following table (*Table 3.5*) shows the improvements from both methods, first using the automatic and after the manual to achieve the highest detection.

This whole process takes a lot of time. As an example we will take the first recording of test subject A, which goes from the original 35% to 72% with automatic processing and finally 90% with the manual detection. That means manual method has increased eye detection by 18%. The recorded video lasts 12 minutes or 720 seconds. The 18% increase in detection is equivalent to modifying the 18% of the 720 seconds, which equals nearly 130 seconds. Being every second 25 frames, the total number of clicks necessary for this improvement is 3,250. This shows the magnitude of the time needed for editing all the videos and all this without taking into account the times when the pupil is detected but in the wrong place. Incorrect detection exists and *figure 3.11* presents a good example of that. This wrong detection has a direct influence on the results and statistics so it is important to avoid them, and for that videos must be completely reviewed.

Table 3.5: *Improvements on pupil detection rate through automatic and manual methods, separated by test subjects A, B and C. Final rate accepted for each recording is in a green background.*

		A		
		Original	Automatic method	Manual method
1st recording. 21st of March.	North-South	35%	72%	90%
	South-North	70%	90%	92%
2nd recording. 14th of May.	North-South	66%	86%	94%
	South-North	96%	-	-
		B		
		Original	Automatic method	Manual method
1st recording. 21st of March.	North-South	33%	50%	90%
	South-North	40%	55%	96%
2nd recording. 14th of May.	North-South	35%	50%	97%
	South-North	45%	49%	96%
		C		
		Original	Automatic method	Manual method
1st recording. 21st of March.	North-South	46%	60%	90%
	South-North	65%	71%	96%
2nd recording. 14th of May.	North-South	86%	-	94%
	South-North	85%	88%	92%

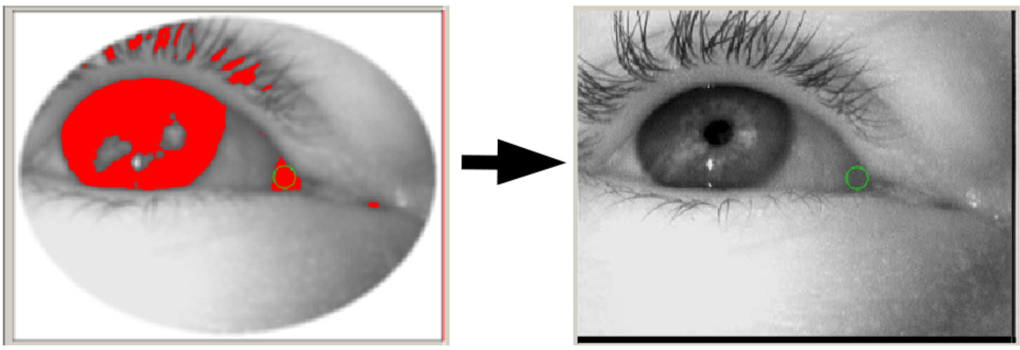

Figure 3.12: *Incorrect eye detection. The red area is all the possible pupil zones, and because it has an area size ratio limit it detects the right corner. Usually this has to be corrected with the manual method by clicking in the pupil.*

3.3.4 Marker detection

Marker detector software is in charge of this step. It is automatic so the only thing to do is choose the directory which it should run over. The software runs over every frame in every video in search for the markers. The real position of the markers can be seen in *figure 3.8*. Each marker is unique and has a name associated which corresponds to a city name. *Figure 3.12* depicts this situation in a schematic way for a better understanding. Hereinafter, the markers will be called by their city name.

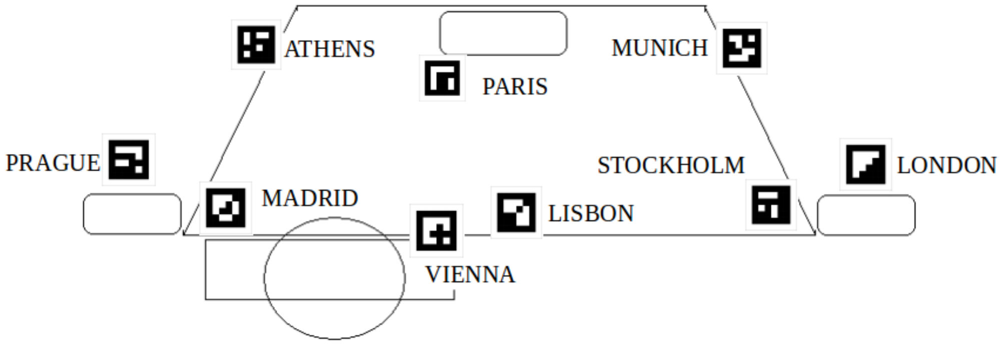

Figure 3.13: *Scheme of the front of the car with markers location with their associated names. This names will be useful to do combinations between the markers and to create AOIs.*

3.3.5 Analysis

Analysis of the recorded data mostly takes place in D-Lab software. Once all the videos have been processed in Dikablis Analysis and afterwards gone through the Marker detector software, it is time to import them to D-Lab and start the analysis.
First of all is the definition of combined markers. Markers are used as references in the view of the field camera so it is interesting to use them for defining and positioning the AOIs. To define later a large AOI, it is better to use combined markers and to attach them to these markers so it will cause the area to be smoother than if attached to only one marker. *Table 3.6* enumerates all the combined markers created:

Table 3.6: *Combined markers.*

Name of the combined marker	**Markers used**
Left mirror	PRAGUE - MADRID - ATHENS
Right mirror	LONDON - STOCKHOLM - MUNICH
Central mirror	PARIS - LISBON
Speedometer	VIENNA - LISBON
Left windshield	PARIS - MADRID - LISBON ; MADRID - LISBON
Right windshield	PARIS - STOCKHOLM - LISBON

The next step is to establish the AOIs. As previously mentioned, these will enable calculation of the percentage of time the subject is looking at them and therefore at the different spots of the car. It will define the gaze behavior and driving patterns of the subjects. These areas are defined as attached to the markers, so every time they are detected, the area will pop up. That is perfect for preventing them from moving along with the head movements. The defined AOIs are shown in *figure 3.14* colored in transparent blue, alongside with their names. The chosen names are the same as the ones for the combined markers. The windshield must be divided in two because the field camera does not cover the whole area.

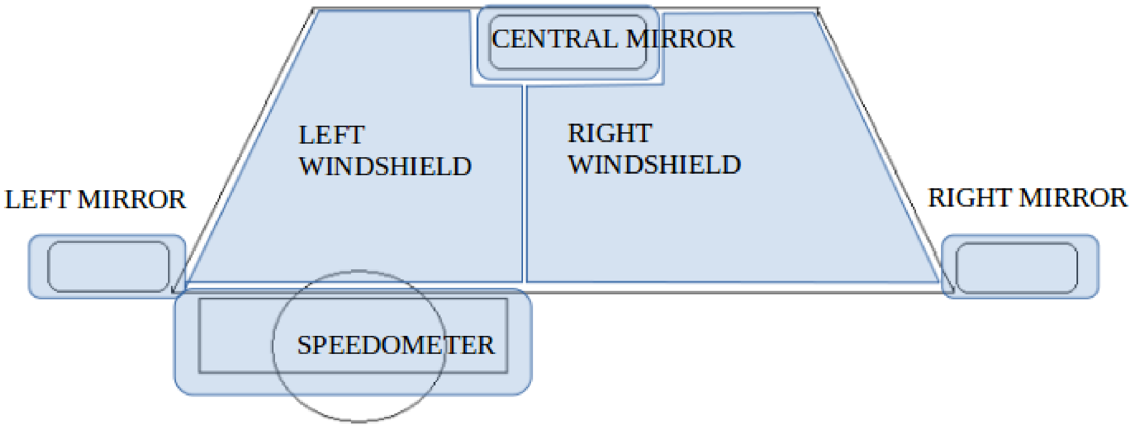

Figure 3.14: *AOIs*

As said every AOI is paired up with one or more markers. Following *table 3.7* presents these pair bondings:

Table 3.7: *Markers and combined markers paired to each AOI.*

AOI	Single markers attached	Combined markers attached
Left mirror	PRAGUE, MADRID	Left mirror
Right mirror	STOCKHOLM, LONDON	Right mirror
Central mirror	PARIS, LISBON	Central mirror
Speedometer	MADRID, VIENNA	Speedometer
Left windshield	ATHENS, MADRID, LISBON	Left windshield
Right windshield	LISBON, MUNICH, STOCKHOLM	Right windshield

AOIs are also paired with single markers so that they appear if one of the markers from the combined ones is not detected and therefore it cannot be represented.

With the AOIs defined, the analysis is ready to become automatic. Gaze can be computed by just pressing the "*Compute gaze behavior*" button. This will return the statistics of the subject's gaze according to the AOIs. Cleaning of the recorded data is required, and it is done with two functions D-Lab provides: blink elimination and cross through elimination (*see Chapter 3.2.2.4: D-Lab*). Blink elimination is set on 200 ms and cross through elimination to 120 ms.

3.3.5.1 Analysis of traffic signals recognition

For the signal detection, Dikablis Analysis is used. This is because it is a manual process were only the recorded video needs to be displayed. With Dikablis Analysis, the exact moment when the driver comes along a signal can be processed to achieve a perfect eye detection and calibration and be 100% certain about where the gaze is pointing at. Once knowing the exact time the driver spots the signal, the behavior will be studied regarding the velocities obtained with the GPS.

4 Results

All the matter information of the twelve videos recorded -four videos for each of the three subjects- has been calculated individually and after put in common. The results presented here are structured as follows:

◆ First, an evaluation of the precision and reliability of the recording. The results have to be trustworthy and they must be presentable for the readers. Terminology such as marker validity (percentage of marker detection through the video) and eye validity (same with pupil detection) will be defined. Markers enable the AOIs and eye validity gives us knowledge about how many time the gaze is inside these AOIs.

◆ Gaze computation. The main focus here is what AOI the subject is looking at and for how long. This will give us a good approximation of the drivers' behavior and patterns. The data values will be studied by AOI, and will include the gaze percentage, number of glances, glance mean time, frequency, etc.

◆ Answering the initial thesis. Are the new implemented traffic signals useful? Trying to see if the subjects recognize the signals and if they modify their driving because of them. Both previous analyses are mostly automatic as D-Lab does the pertinent calculations but the last one is more manual. GPS data is of great importance as it stores the coordinates and its paired velocities. The applied methodology to obtain these results will be comparing the road sections where the signals are positioned in both the first and second recording.

4.1 Validity of recordings

To study the reliability of the recordings, we focus on two data values: marker and eye validity. These values are measured by the percentage of detection, i.e. the time they are recognized by the software in front of the total time of the recording. They are automatically calculated by D-Lab software after the "gaze behavior" is computed. Eye validity depends strictly on the processing work done in Dikablis Analysis and the values differ minimally from those obtained in *Chapter 3.3.3: Processing*. Marker detection relies on the capacity of the field camera. It must be well focused before recording so as to achieve maximum clarity of the image and minimum blurriness of the markers . The following tables present these values.

- **Test subject A**

Table 4.1: *Reliability of the recordings based on marker and eye validity for test subject "A". Values obtained directly from D-Lab software*

	1st recording. N-S	1st recording. S-N	2nd recording. N-S	2nd recording. S-N
Marker validity	91,95%	90,38%	70,80%	93,42%
Eye validity	94,38%	91,53%	94,16%	96,33%

- **Test subject B**

Table 4.2: *Reliability of the recordings based on marker and eye validity for test subject "B". Values obtained directly from D-Lab software.*

	1st recording. N-S	1st recording. S-N	2nd recording. N-S	2nd recording. S-N
Marker validity	93,29%	93,80%	98,86%	98,54%
Eye validity	90,97%	90,06%	91,40%	90,86%

- **Test subject C**

Table 4.3: *Reliability of the recordings based on marker and eye validity for test subject "C". Values obtained directly from D-Lab software.*

	1st recording. N-S	1st recording. S-N	2nd recording. N-S	2nd recording. S-N
Marker validity	90,12%	95,89%	98,03%	97,60%
Eye validity	93,43%	96,80%	94,68%	94,09%

As can be seen, eye validity values are all above 90%, which is expected as all the processing with Dikablis Analysis is behind. Those are really good results based on which gaze behavior can be studied correctly. On the other hand, marker validity is also good except for the 2nd recording N-S for test subject A. The reason for this could be that the field camera lost its correct focus at some point and together with the cloudy weather it decreased the markers visibility. This loss of marker detection leads to the loss of AOIs appearance in the video. As explained in previous chapters, AOIs are linked to markers and when none of these are detected, they do not show up and consequently no gaze is computed. Even so, eye validity is really good and traffic signal recognizing can be studied in the same manner.

4.2 Gaze statistics

D-Lab has the option to compute the gaze behavior automatically based on the gaze point and the AOIs. First table represents the percentage (%) the gaze spends in each AOI (*table 4.4*).

Table 4.4: *Percentage of time spent in each AOI. LM - Left mirror, RM - Right mirror, CM - Central mirror, LW - Left windshield, RW - Right windshield, SP - Speedometer. Last column displays the sum of all percentages.*

RECORDING	LM	RM	CM	LW	RW	SP	SUM
A 1 N-S	7,50	2,50	2,11	77,85	0,41	0,67	91,04
A 1 S-N	6,00	1,90	3,55	74,98	0,28	1,62	88,34
A 2 N-S	1,85	1,10	4,90	70,82	0,99	0,18	79,84
A 2 S-N	3,51	0,30	2,89	85,16	0,20	0,44	92,51
B 1 N-S	9,32	0,90	5,00	72,63	0,28	1,09	89,23
B 1 S-N	8,75	3,10	4,89	78,28	0,75	0,27	96,05
B 2 N-S	3,60	1,01	5,88	85,48	0,76	1,10	97,83
B 2 S-N	4,50	1,00	3,78	84,82	0,80	1,80	96,70
C 1 N-S	7,34	2,20	3,99	66,65	0,46	3,46	84,09
C 1 S-N	8,44	2,98	4,21	77,63	0,68	2,41	96,35
C 2 N-S	4,30	0,88	4,88	79,91	0,39	1,30	91,66
C 2 S-N	7,50	0,97	1,80	83,50	0,42	2,96	97,15

An interesting and a good fact at the same time is that the tendency is quite similar for all the recordings. That makes sense as the driving patterns for users are usually equal; people in the same driving situations (crossroad, straight road, turns, etc.) tend to look at the same areas. The most observed AOI is obviously the left windshield, as the road hoards nearly all the attention. The mean of the left windshield percentage is 77.78% with a standard deviation of 1.69. It is during this time that the traffic signals are to be recognized. They could also be in the right windshield if the signal is detected late but this AOI has a really low percentage of gaze in it. The last column "Sum" represents the sum of the percentages of each recording. It is not 100% because there are some gaps between the different AOIs so gaze is not pointing anyone.

Another detail is the low percentage of mirror use. It is known that the recommended norm for using the mirrors is every five to eight seconds [4.1 as an example]. If we take a look at *table 4.5*, we see this does not happen. Compared with the recommended frequency (1time/8 s = 0,125 s^{-1}), the results obtained are significantly smaller even with the sum of all three mirrors. The studied road is a two-way two-lane road so the issues may come from the front. This can explain why mirrors are not so well observed.

Table 4.5: Glance frequency of the mirrors.

	Glance frequency [s⁻¹]			
Recording	**Left mirror**	**Central mirror**	**Right mirror**	**Sum**
A 1 N-S	0,029	0,077	0,009	0.115
A 1 S-N	0,046	0,032	0,003	0.081
A 2 N-S	0,056	0,044	0,007	0.107
A 2 S-N	0,087	0,026	0,003	0.116
B 1 N-S	0,032	0,049	0,024	0.105
B 1 S-N	0,033	0,046	0,014	0.093
B 2 N-S	0,067	0,053	0,033	0.153
B 2 S-N	0,059	0,044	0,007	0.110
C 1 N-S	0,048	0,032	0,020	0.100
C 1 S-N	0,034	0,091	0,015	0.140
C 2 N-S	0,045	0,096	0,009	0.150
C 2 S-N	0,087	0,071	0,014	0.172

4.3 Traffic signals recognition

This chapter's objective is to see if the drivers recognize the signals, and if they do, see what is their reaction to it in terms of speed variation. First the drivers will be studied individually, comparing their before and after recordings, and afterwards the results will be put in common.
Before starting the driving behavior of the subjects, validity of the road studied must be demonstrated. *Figure 4.1* shows the road based on the coordinates obtained with the GPS. As seen is the exact path as the one seen in *figure 1.2* in *Chapter 1.1: Background and motivation*.

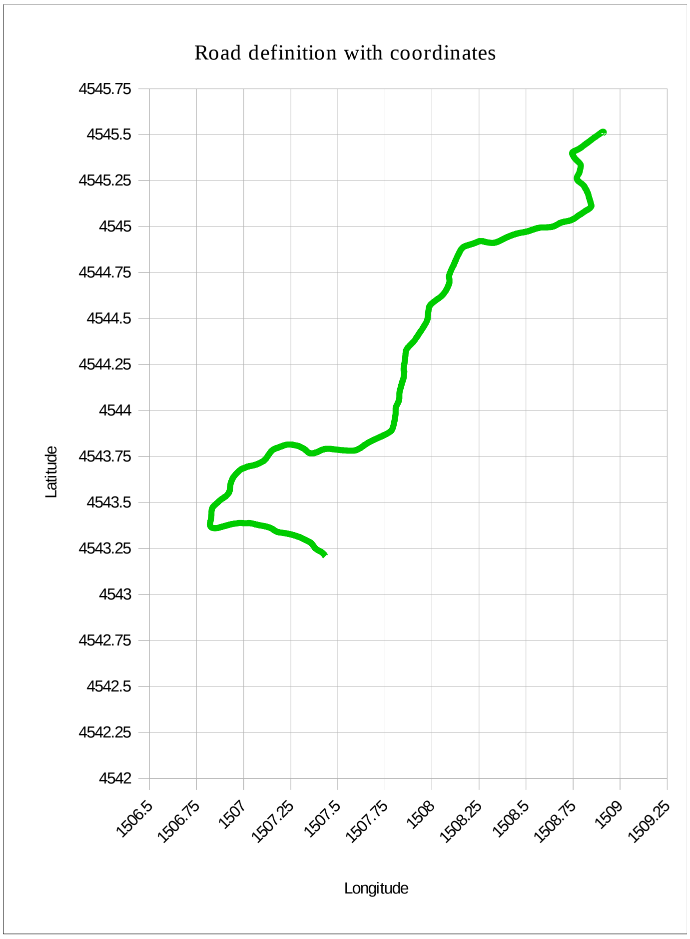

Figure 4.1: *Road definition based on the coordinates obtained with the GPS.*

The following *figures 4.2 to 4.10* shown in this chapter display the speed variation in time graphic for the test subjects for both South-North and North-South route or from km 16,700 to km 7,365 and vice versa. The ideal would be to have all 12 graphics but technical problems with the GPS as overwriting previous data or unexpected disconnection led to missing data; specifically in "test subject A 2nd recording N-S" and "test subject C 2nd recording N-S". This missing data makes it impossible to analyze the speed variation and therefore the driver behavior precisely. However, the signal detection can still be studied with the Dikablis recordings. Also, on the day of the second recording signals 4 and 4a were not implemented, so they will not be taken into account, and signal nº 9 is not included in the stretch of road under study. The analysis will be done as follows: with the recorded data from the GPS a speed vs. time graphic is obtained. Then the signals are spotted on the recorded videos (second recordings as they are the ones with signals). The idea is to catch the exact moment the driver first notices the signal (when the cross-hair first points at it), register the time when this happens and check what is happening in the speed variation graphic. The time when the GPS starts recording is not always the same as the time the video starts recording so there is a delay and that has to be taken into account. This delay is countered using the moment the car begins to move, as both clocks can be synchronized then – the video clock by watching when the car starts moving and the GPS clock by searching the point the speed stops being zero. Once the times are matched, the exact moment of signal recognition can be placed in the graphic and analyzed. The signals are placed as dots in the line of the graphic. In the first recordings, orange dots represent the moment the signal should be spotted by the driver. In the second recordings graphic, when the signals are already installed, green dots represent the detected signals and red dots the not detected ones. The graphics are complemented with a table for a better understanding of the mentioned signals and the reactions they lead to. In these tables, a green colored box presents a detected signal, red box not detected and "Miss" when data from that signal is missing, for example when in "test A 2nd recording S-N" the driver took the wrong path. Driver behavior against this signals is analyzed individually and for each of them.

4.3.1 South-North recordings

- **Test subject A**

Figures 4.2 and *4.3* display the speed variation graphic for test subject A in the South-North route:

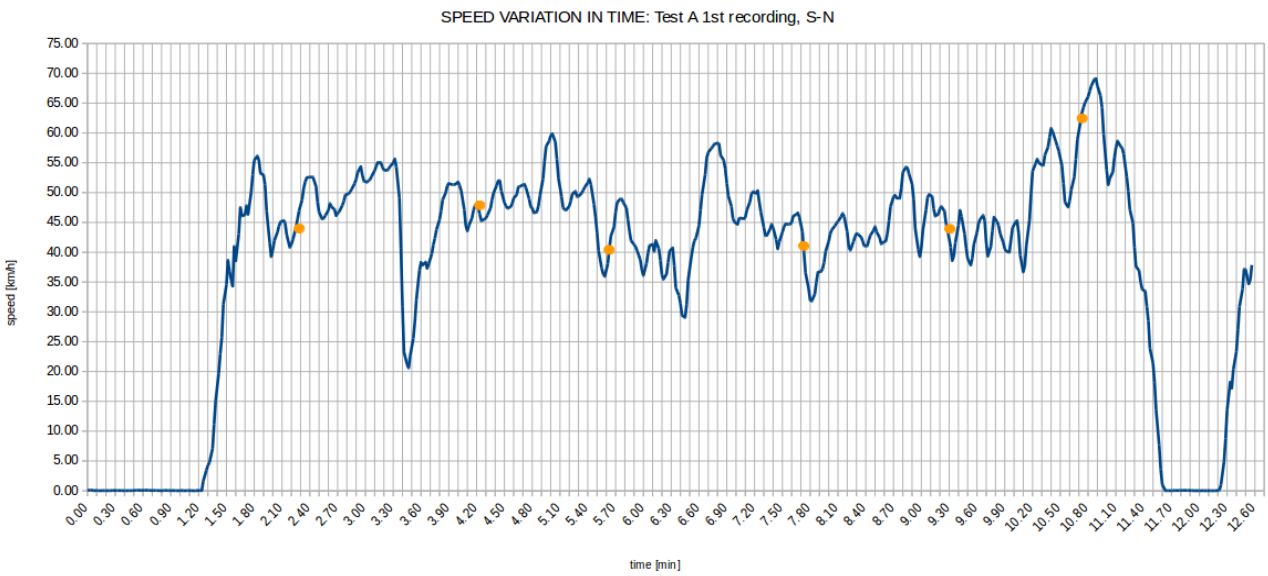

Figure 4.2: *Speed variation graphic: subject A 1st recording S-N*

The first graphic (*figure 4.2*) shows a constant range of velocities between 60 and 40 km/h. In all graphics, it is similar as it is the prudential speed on such roads. Small variations of speed are constant and mostly due to turns, poor visibility areas or other cars driving in the opposite direction. Also evident in all recordings is a big speed decrease (in this first *figure 4.2* it takes place at min 3.3) induced by a crossing with the train rails close to km 16.7. In the first recordings, it can also be seen how sometimes the car stops completely for one to two minutes. The reason for that is there was a stretch of road under construction and the two lane road turned into a one lane road with a regulating traffic light. By the time the second recordings were performed, it was already finished.

Figure 4.3 shows something special: two orange lines crossing the speed line. All the points in between these two lines correspond to wrong recorded data as the driver "A" took the wrong path, with the consequence of skipping signal nº3. The breaking at the end of this wrong path, which slows down to 5 km/h, corresponds to the yield before the incorporation to the road again. Signal nº8 is detected in the video, but it does not appear in the graphic as the GPS stopped recording data before the end.

Table 4.6: *Signal recognition: subject A 2nd recording, S-N*

Signal	Detection	Drivers behavior
1		The driver sees the signal and slows down before entering the turn. If we look at the 1st recording he keeps accelerating until the turn comes, not before. In the straight after, speed increases in both drives.
2		The driver is already slowing down as entering a stretch of road with houses to the sides. He only notices one of the two signals. Keeps decreasing until more visibility.
3	Miss	No possibility to notice sign 3 as he took the wrong way.
4		-
4a		-
5		Misses signal as it is in the other side of the road. Keeps increasing speed slowly for 10 seconds until the next turn that appears (min 8).
6		Notices the signal more than 100 meters away. It is located in a long straight stretch wit a lot of visibility. He stops accelerating the car as he approaches the signal, decreases 3-4 km/h and then continues accelerating until a turn appears with not much visibility due to the trees and vegetation.
7		Clearly notices the signal. As in nº6 he stops revving the engine as he sees it. This can be perfectly appreciated as well as how it does not happen in the 1st recording, where it keeps accelerating. The following 27 km/h decrease stands for a parked car and an incoming car from a change of grade in the opposite direction.
8		Detection. Slows down after as it is the end of the test.

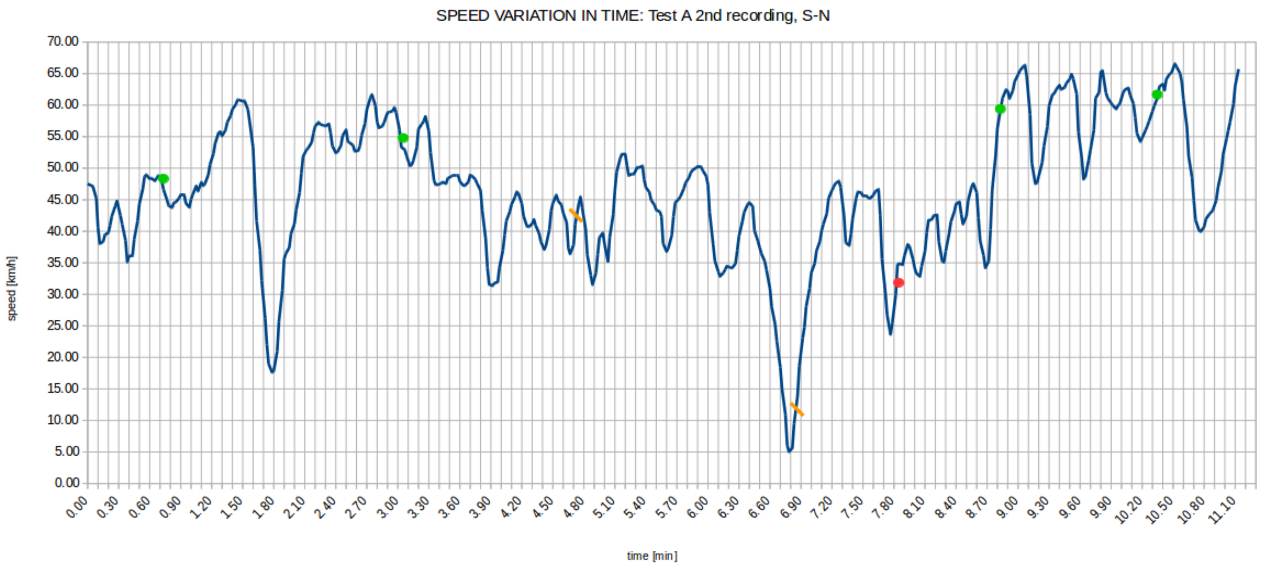

Figure 4.3: *Speed variation graphic: subject A 2nd recording, S-N*

- **Test subject B**

Figures 4.4 and *4.5* display the speed variation graphic for test subject B in the South-North route:

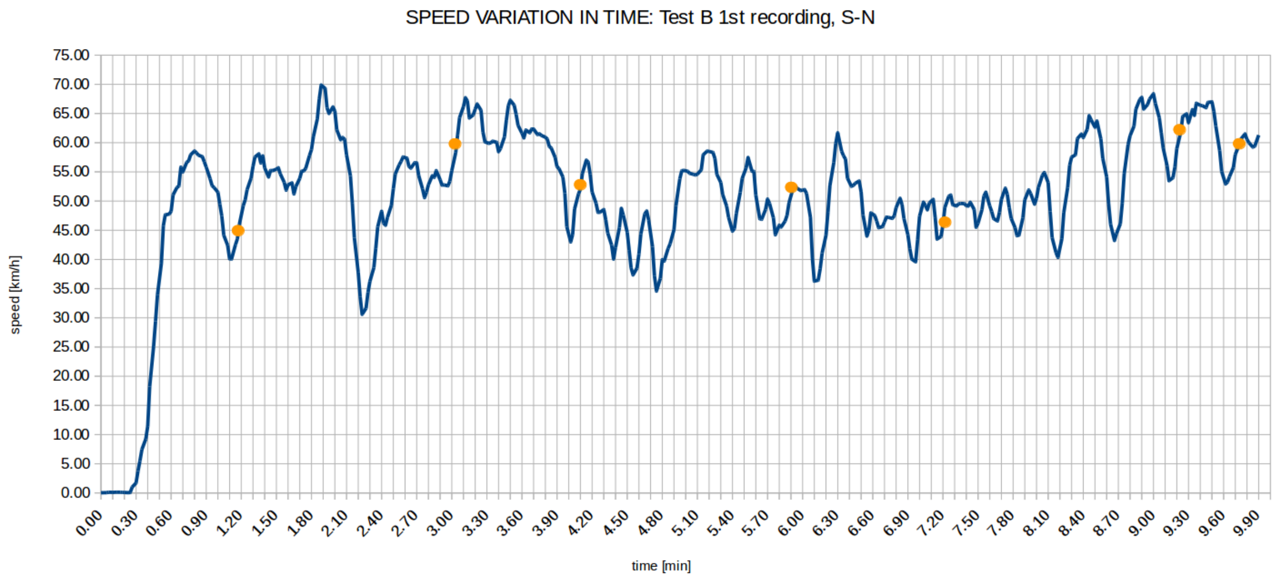

Figure 4.4: *Speed variation graphic: subject B 1st recording, S-N*

Looking and comparing the two graphics we can see a lot of similarities in the driving which is obviously normal as the driver and the road are the exact same. But going into the details is how we start noticing differences and most of them have to do with the signals. Where the 1st recording data shows how after the signals the car keeps accelerating the 2nd one shows how the driver breaks or lifts the foot of the accelerator to ensure safety. A few examples can be highlighted as signals nº2, nº3 or nº6 among other.

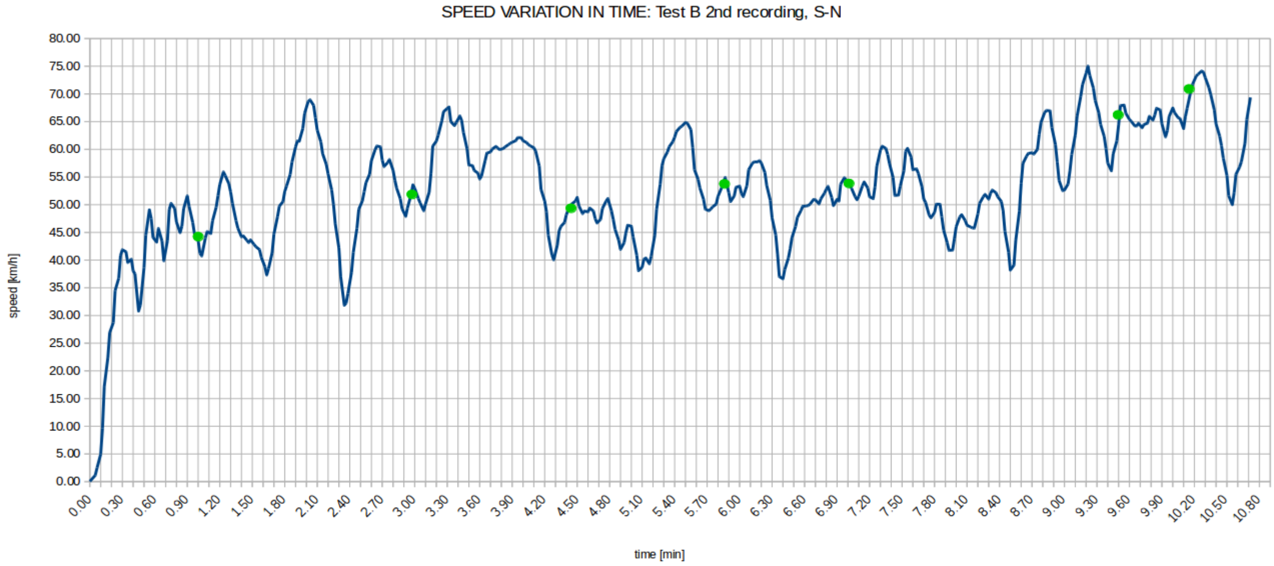

Figure 4.5: *Speed variation graphic: subject B 2nd recording, S-N*

Table 4.7: *Signal recognition: subject B 2nd recording, S-N*

Signal	Detection	Drivers behavior
1		The driver is slowing down as he sees a truck with the lights on parked. Just after it, he looks at the signal and just after the signal he sees a man working on the sidewalk who he had not noticed before. As he was already slowing down for the truck, he keeps doing it until he passes by the man and it is a safe situation to accelerate. In the first recording he is accelerating as he does not have any situation ahead, truck or signal.
2		While entering the stretch of road with houses to the side he begins slowing down calmly. Next he detects both signals, left and right, while he was already accelerating so that makes him break softly again.
3		Easy detection; stops accelerating, contrary to the 1st recording.
4		-
4a		-
5		Detection really close to the moment he is about to pass the signal. Decides to stop accelerating and maintain speed until the next curve.
6		Notices the lighting signal as its in a good visibility stretch. Maintains speed as keeps focusing the signal from time to time. As he approaches the signal and sees no trouble, he accelerates and only breaks because of the presence of incoming cars.
7		As he is driving at one of the highest speed of the test, he realizes the 7th signal. Maintains speed as visibility is good and after accelerates as the road turns into a descent.
8		Notices signal from far distance but begins breaking because it is the end of the test.

- **Test subject C**
-

Figures 4.6 and *4.7* display the speed variation graphic for test subject B in the South-North route:

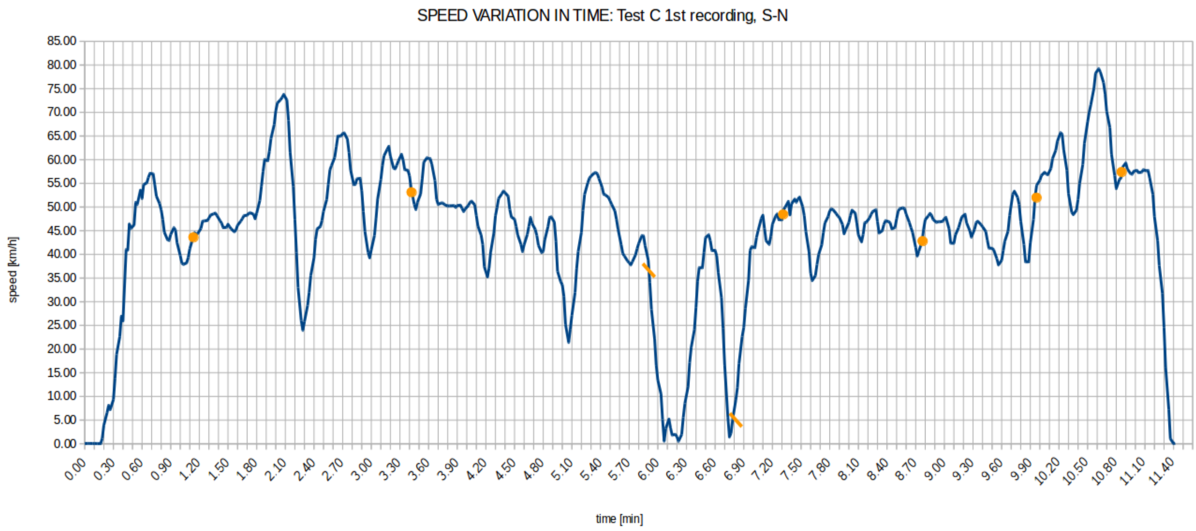

Figure 4.6: *Speed variation graphic: subject C 1st recording, S-N*

In *figure 4.6* the orange lines are again present as driver C made the same mistake driver A made in the 2nd recording. The difference is he stopped, turned around and went back to the place of confusion. That is why there is a first stop, followed by some reverse driving, then stopping again and leaving (minutes 5,80 to 6,50). The next big speed decrease (minute 6,75) corresponds to the yield again before incorporating to the previous road. Again both graphics show really similar behaviors. GPS for the 1st recording did not make it to the 8th signal so last one seen is the 7th.

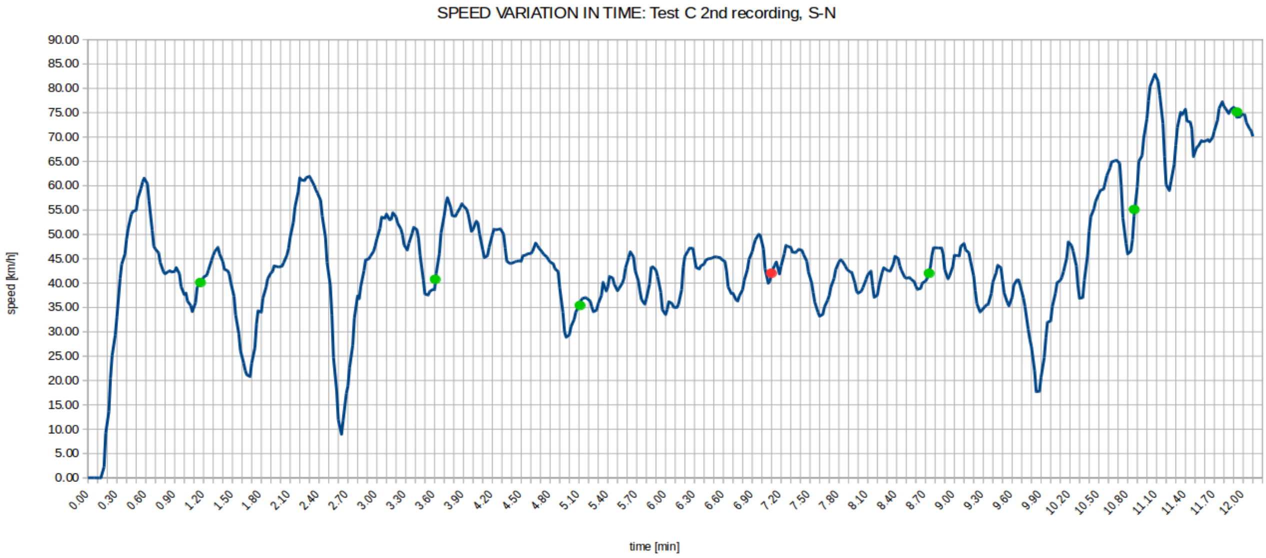

Figure 4.7: *Speed variation graphic: subject C 2nd recording, S-N*

Table 4.7 gives the detailed explanation of the detected signals and the drivers reaction to them:

Table 4.8: *Signal recognition: subject C 2nd recording, S-N*

Signal	Detection	Drivers behavior
1		Was driving at a prudential speed because of a lorry passing by closely. Just after the lorry he accelerates again and immediately notices the signal. The low speed allows him to keep accelerating while staring at the signal and its surroundings.
2		As he enters the stretch with houses he drives prudentially and spots both exiting signals at nº2. Has time to see if there is danger situation or not while accelerating.
3		Sees the signal and there is good visibility. Slows down when entering the curve.
4		-
4a		-
5		Misses the signal. He has to slow down just before because of a truck coming from the other direction and then starts accelerating again. The signal is in front of another truck which is parked so that can help to the non detection of it.
6		Notices from far distance as it is a lightning one. and the road has good visibility. No need to brake, speed can be maintained at a reasonable level (~50-60 km/h)
7		Slows down when he sees a van arriving from a crossroad. When the van stops he continues and looks at the signal and its sorroundings to see that there is no danger. Then he keeps accelerating.
8		Recognizes the signal, starts breaking as its the end of the test.

4.3.2 North-South recordings

- **Test subject A**

Figure 4.8 displays the speed variation graphic for test subject B in the first recording South-North route. As previously mentioned, in the first recordings there was a stretch of road under construction and this is reflected between minutes 7 and 8.8, when the car stops because of the red light. The test actually begins at minute 2.4 as the ride to the starting point is recorded by the GPS. All the speed graphics show great similarities between the drivers (*see figures 4.8 to 4.11).* As previously mentioned, the data from the second recording is missing so it cannot be compared with the first recording, but signal recognition has been studied. *Table 4.9* presents these results. Note that the numeration starts with 8 and ends with 1 as the driving is in the opposite direction.

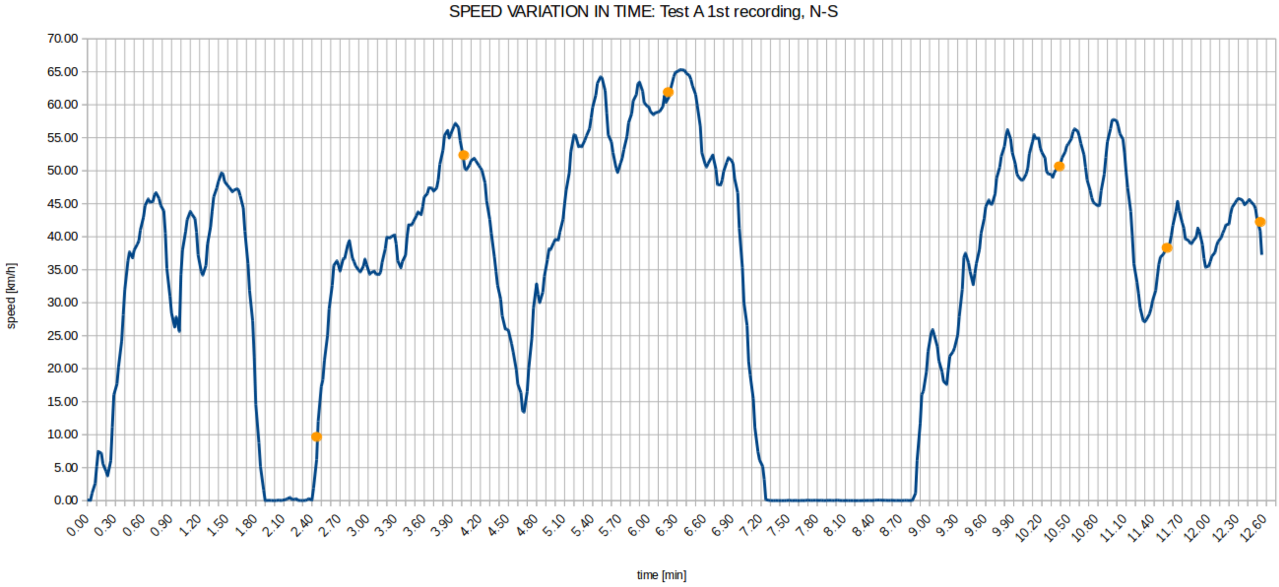

Figure 4.8: *Speed variation graphic: subject A 1st recording, N-S*

Table 4.9: *Signal recognition: subject A 2nd recording, N-S*

Signal	8	7	6	5	4a	4	3	2	1
Detection									

Also to be mentioned in all three subjects signal nº8 won't be participating as the drive started after it so the first one possible to detect is nº7.

- **Test subject B**

Figures 4.9 and 4.10 display the speed variation graphic for test subject B in the South-North route:

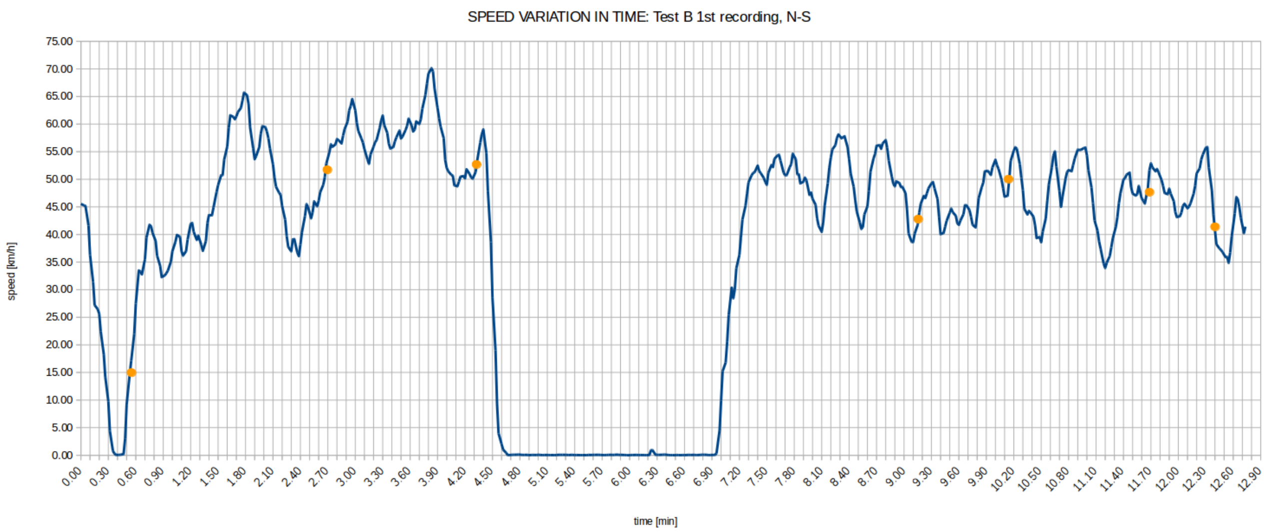

Figure 4.9: *Speed variation graphic: subject B 1st recording, N-S*

Note again in *figure 4.9* the 2 minute stop due to the traffic light. Watching also both graphic we see the great similitudes in driving, with nearly the same increases and decreases of speed. But looking closely to the moments the signals are noticed differences can be seen. Signals nº5 or 3 show differences in the behavior as in the 2nd recording -the one with the signals- we can observe tiny decreases of speed due to a reaction against the signal.

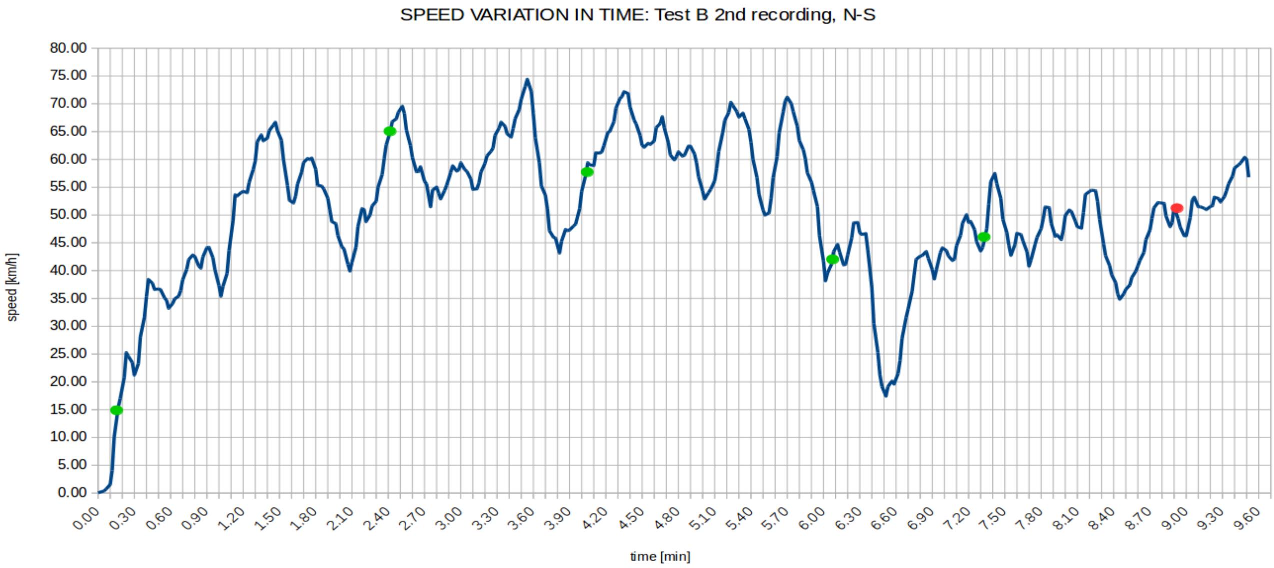

Figure 4.10: *Speed variation graphic: subject B 2nd recording, N-S*

Table 4.10: *Signal recognition: subject B 2nd recording, N-S*

Signal	Detection	Drivers behavior
8		-
7		Signal noticed just after starting the drive. There is no modifying of driving as the speed is very low. Following decrease of speed is for caution in front of another car driving towards him.
6		Easy detection as it is lighting signal. Decreases speed as approaching it as it is placed in a change of grade stretch. After he accelerates into a descent so reaches high speed.
5		Accelerating until he sees the signal what makes him leave the gas for a moment to check sidewalks. He continues until a car and stopped truck make him lower velocity.
4a		-
4		-
3		In this direction the signal is placed after a closed curve, what makes the driver stop accelerating when he sees it. Note the difference with the 1st recording where he keeps accelerating.
2		Only sees the signal in the right side. The one in the left from this direction is covered partially by a mirror which difficults its detection.
1		There is a lighting truck in front of the signal. This plus the tree in front of the signal makes him miss it. However the truck makes him slow down.

- **Test subject C**

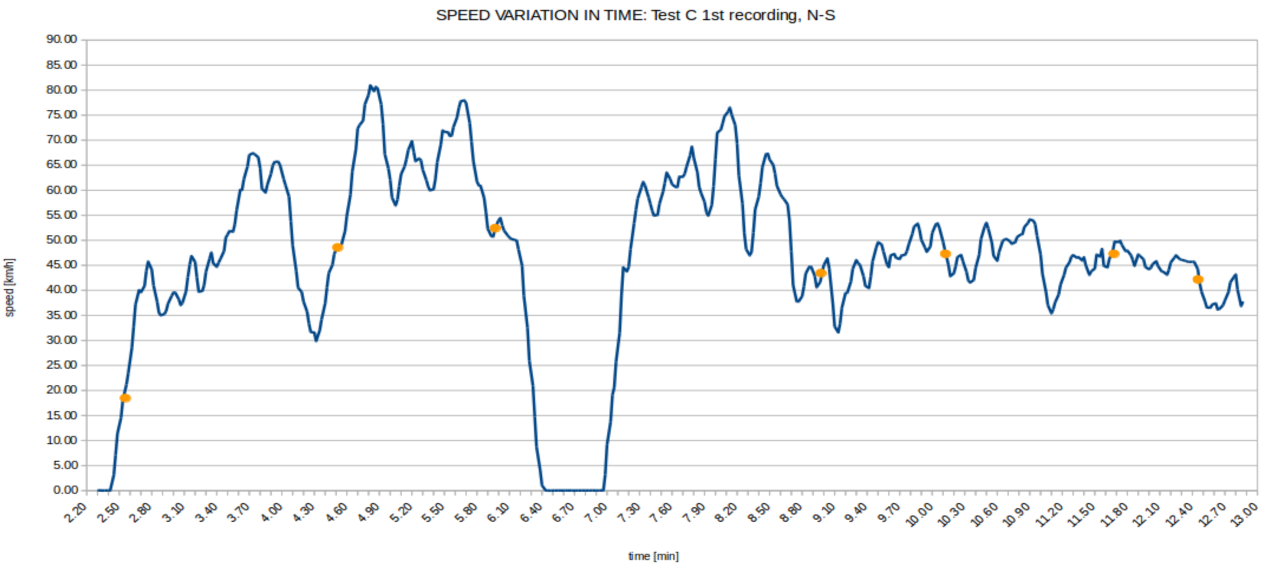

Figure 4.11: *Speed variation graphic: subject C 1st recording, N-S*

The graphic presents very similar results as the other first recordings as expected. As in subject A the data from the 2nd recording is missing so only the signal detection has been studied.

Table 4.11: *Signal recognition: subject C 2nd recording, N-S*

Signal	8	7	6	5	4a	4	3	2	1
Detection									

Detection is very good except for signal nº1 where the same thing as in subject B happens; the lighting truck is still in the same parking spot with the lights on so distracts completely the driver.

4.3.3 Detection

Table 4.11 collects all the information for a general overview. As seen 34 out of 38 possible signal detections have been achieved. Only four times the signals have not been recognized, and mostly because of external distractions.

Table 4.12: *Total signal recognition. In green the detected signals, in red the not detected and in black the impossible to detect.*

	2nd recordings signal detection						
	South-North			North-South			
Signal	A	B	C	A	B	C	Signal detection
1							4 / 6
2							6 / 6
3							5 / 5
4							-
4a							-
5							4 / 6
6							6 / 6
7							6 / 6
8							3 / 3
Total	5	7	6	6	5	5	34 / 38

5 Discussion

Three drivers have been tested along the same stretch of road before and after the implementation of new traffic signals to decide whether they are useful for improving the road safety in Novo Mesto. This of course can be extrapolated to overall road safety because if it works for this town, it could prove helpful for any other town with the same road conditions. The initial thesis of this project was that these signals are useful for the intended purpose and will make children's way to school significantly less dangerous, and at first sight it seems like it is going to be proved correct.

First of all, the Dikablis system must be reviewed as the results rely on it. The eye tracker used dates from 2009 but its precision in eye detection, marker detection and calibration matches the capacity of today's eye trackers. Its possibility to process the recorded data makes its accuracy unbeatable. As demonstrated in *chapter 3: Methodology* and in *chapter 4: Results*, eye and marker detection always achieve (except in one case for the marker detection) values over 90%. This translates into a high reliability of the further obtained results.

One of the biggest challenges met in this study is the sunlight. The device in closed rooms with no sun reflections works perfectly to the point where it does not need any posterior processing but recording in the outside may cause some trouble. It can be observed and it is explained in *chapter 3.3.3: Processing* that on a cloudy day (second recordings) the results on eye detection are much higher than those obtained on a sunny day (first recordings). This problem is still not solved and even nowadays eye tracker providers recommend avoiding intense lighting impacting the eye or eye tracker camera. As well as reflections, it causes constant changes in the pupil size which impoverishes the detection. So to enable maximum quality experimentation and minimum processing after the recording, no light environments are recommended. This project analysis is mostly manual as signals must be noticed by human eyes in the video, but a really important aspect is the experiment setup. Markers have to be precisely placed for its detection and a first trial test should to be done to prove their recognition. Otherwise, the results can be altered and insufficient or inadequate. Another advantage of today's eye trackers is improved ergonomics. Dikablis 2009 is a rather uncomfortable device completely wired which requires careful handling all the time. Tiny movements can produce unclear or untrustworthy results. All these setbacks have been studied and overcome with success, but they have to be taken into account nevertheless.

The focus of this project is the signal recognition and the reaction in behavior they produce. In "*table 4.11: Total signal recognition"*, the final results are presented. 34 out of 38 possible signals have been detected. Only four of them were unspotted and only due to other reasons than the driver's attention such as trucks in the way, other signals, etc. Two out of the seven studied signals were a lighting type and the rest were static. The most detected signals are 2, 3, 6, 7 and 8 with a 100% rate of recognition. This means they are really well placed and visible. Nº5 and 1 have a 66.67% rate of detection which is also high. The reason nº5 is not visible sometimes is because it is only on one side and from the S-N route it is sometimes difficult to spot. Nº1 could have been 100% easily but the presence of the lighting truck prevented this situation. The signal has a light and is visibly located so people should not have any difficulties seeing it. So the final result is 89% detection and the remaining 11% of non detection cases are due to specific road situations, which makes it a perfect outcome for the study.

In terms of drivers, the three had excellent results. From the six drives, two of them had 100% detection (B S-N and A N-S) and the other four only had one failure. It has to be said that the conditions were set for experimentation and the subjects knew they were being tested but they did not know the nature of the tests. Better data could have been collected from unaware subjects but with this eye tracker this situation is impossible as it requires significant setup. Also, more data would enable more reliable results. Only three subjects and six drives may not seem enough to roundly conclude that signals will always be detected and will therefore induce some change in the driving behavior of people. Some factors that do not take part in our experiment can have an impact on noticing signals, such as age of the driver, years of experience, instantaneous situation (e.g. is the person in a hurry, are there people in the car causing other distractions, etc.). Despite this, the results obtained seem promising for a great project which aims to grow and prevent road accidents, a real problem that has been present through ages and improve children’s safety.

To conclude, we must answer the initial hypothesis: "*The new traffic signals are very useful and prevent the possibility of accidents as drivers notice them and react to them".* Based on the results obtained, the answer is ‘yes’. Drivers detect the signals and there is an evident change of behavior in most cases, which consists of lifting the foot from the accelerator pedal for a second or two seconds at least and looking around. After noticing the signals, they take a look at the surroundings and even look at the signal again. So it is true that they are modifying the drivers’s behavior and helping them keep focused on points where children safety is compromised. Even though test subjects can be insufficient and there is some missing data needed to reach 100% conclusions, the results show minimum error and are promising for further work on the project.

6 Conclusions

This chapter summarizes the most important bullet points of the chapters seen previously.

- In the introduction the road section under study is defined. The experiments were performed on the Section 2501 of the State road R3-664 near Birčna vas outside Novo Mesto from km 7,635 to km 16,700. Nine signals were to be implemented in this segment. Finally the studied signals are seven: 1, 2, 3, 5, 6, 7, 8. Signals 4 and 4a are not placed yet and signal 9 does not take part in the experiment a sit is not in the road stretch defined.

- Theoretical background puts in context the eye tracking technology and explains the previous work started during the Master Practicum. We researched the device whole functioning to obtain the most of it. Conclusions of it where that the experiment set up is very important to obtain the most reliable results. Eye detection, gaze calibration and marker positioning configure this set up. Eye calibration is for detecting the pupil in every moment and track the gaze changes. Gaze calibration is for relating the pupil position in the eye camera with the field camera and then know the exact place of the road where the eye is pointing. Marker positioning wisely chosen facilitates the further analysis and enables the creation of the most adequate AOIs. Also, the importance on choosing the best day for recordings as sunlight impoverishes the results, so the best days are cloudy ones. So in conclusion, preparing the perfect scene before recording allows to obtain the best results with the less processing afterwards.

• Dikablis system worked perfect for our purpose. The device is easy to use and even though it requires a lot of material transportation for the experiments, it can be comfortably fit into any car. The head-unit was sensible as the screws weren't completely fixed and the drivers had to be careful to not deviate the cameras position. Settling a good field camera focus is really important as the image quality and therefore the marker detection are much better. It has to be done before every experiment, as the eye and gaze calibration.

• Three test subjects were tested in two different days, before and after the implementation of new traffic signals. First recording day was sunny so the data had to be processed later at a high level. Second recordings were on a cloudy day so the eye tracking data quality was much better. The experimentation was successfully carried out and data was correctly collected.

• The results show that first of all, the recordings validity is great. All eye detection rates are above 90%, and marker detection too except for one recording at 70%. This percentages gives full reliability to the further results and conclusions. Analysis of the driving behavior with the AOIs and gaze computation display normal driving patterns for what should be expected in this type of road. Signal recognition was also really high, as 34 of 38 possible were detected (~90% detection), and the not detection of the other four where caused by external common distractions. This means the signals chosen positions make them completely visible for drivers. Except signal nº1 and nº5, all the other signals where 100% detected.

• The new signals modify the behavior of the drivers. They make them stop accelerating to take a look at the proximities of the signal and examine the possible dangers. If no danger is detected they continue the drive but as they noticed them, they do it in a safer way. This gives an idea of how useful the signals can be.

6.1 Future improvements

Eye tracking is an old technology and his development has been a long process over the years that is nowadays starting to see the results. And it is every time entering more and more fields of study helping in the obtainment of data and solution of problems. The future looks like it will include numerous ways of wellness improvement by the continued application of eye tracking technology.

Fields of use in which eye tracking is more commonplace (psychology, advertising, human factors, etc) are also benefiting from the increased knowledge of their use, as well as the increased accessibility. The number of publications within each field using these devices continues to grow year on year. Some of the fields where eye tracking have shown great promise to make the most of the increasingly accessible technology are : VR and AR, health (medical treatment, mental health diagnosis, etc.), sports and eSports and future generation of video games. In health care, research has shown how eye tracking can help predict the performance and accuracy of interpretations made by nurses when assessing vital signs in a clinical context. By using these findings to structure future training, or even the design of the clinical space, the method of delivering medicine could be greatly improved. An important field also in medical treatment is the creation of assistance technology solutions that help people with disabilities to communicate and be independent, like cerebral palsy or ASD (Autism Spectrum Disorder). By using an eye tracker and a software this people can fully use the software with their eyes. For example, the TM5 [5.1] is a fast, accurate eye gaze camera allowing you to control your device with your eyes. With full integration with Grid 3, the EyeTech

TM5 is an excellent choice for communication, computer control, environment control and interactive learning. Simple configuration allows you to take complete control of the Windows desktop, with mouse control and options for clicking and doubling clicking.

Eye tracking in driving has also a promising future in improvements. Nowadays the company Tobii already provides his technology into vehicles [5.2], aiming to help in different aspects: detecting drowsiness via eyelid closure, detecting distractions warning when the eyes are for too long off the road, personalization by recognizing the driver and adapting automatically his preferences or gaze interaction (control the dashboard with the eyes). But field of bigger projection is autonomous driving. The car must reach a symbiotic relation with the driver and eye tracking is a necessary tool. Only eye tracking can tell the car where the driver is paying attention, what information he has they've processed and if he is fit for duty. Also, deep learning from observing human interaction with the road, other vehicles and surrounding objects or pedestrians. The autonomous car is near and eye tracking will be present for sure.

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